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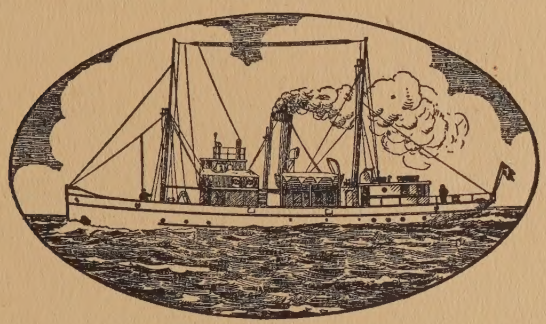
Report

of

The Danish Biological Station

to

The Ministry of Agriculture and Fisheries



XLVII.

1942.

By

H. Blegvad, Ph. D.
Director

Copenhagen. C. A. Reitzel.
1945.

The Reports from the Danish Biological Station (Nos. I—XXI) are published in the official Danish "Fiskeri-Beretning" for the years 1890—91 until 1912. After this year they appear as special publications. The Reports I—XXXII are edited by Dr. C. G. Joh. Petersen, the Reports XXXIII—XXXVI by Dr. A. C. Johansen and the later Reports by Dr. H. Blegvad.

I. *C. G. Joh. Petersen:* Fiskenes biologiske Forhold i Holbæk Fjord. (1890—91)*) 63 pp. 1 Chart. Out of print.

II. *Idem:* On the Eggs and Breeding of our Gobiidæ. (1891—92.) 9 pp. Two Plates. Out of print.

III. *Idem:* The Pelagic Life in Fænø Sound etc. (1892—93.) 38 pp. Tables. Out of print.

IV. *Idem:* On the Biology of our Flat-fishes and on the decrease of our Flat-fish Fisheries. (1893—94.) 146 pp. 2 Plates. 1 Chart. Many Tables. Out of print.

V. *Idem:* The common Eel (*Anguilla vulgaris* T.) gets a Particular Breeding-dress before its Emigration to the Sea. (1894—95.) 35 pp. With 2 Plates.
Etc. 64 pp. Out of print.

VI. *Idem:* The Yearly Immigration of young Plaice into the Limfjord etc. (1895—96). 48 pp. 1 Chart. 2 Tables. Out of print.

VII. *Idem:* Plankton-Studies in the Limfjord. 1897. 23 pp. 1 Map. 4 Tables. Out of print.

VIII. *Idem:* An Otter-Seine for the Exploration of Deeper-Seas. 1898. 24 pp. With 10 Figures. Out of print.

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X. *Idem:* List of the "Aalerusestader" in Denmark etc. — Smaller Communications. 1899 and 1900. 37 pp.

XI. *Idem:* I. The Biology of the Cod in the Danish Seas. II. On other Codfishes in our Seas. III. Some General Observations on Protection, Legislation etc. IV. Alterations and Improvements on Otter-seines for Zoological Purposes. 1900 and 1901. 44 pp.

XII. *Idem:* I. Where, and under what Conditions, can the Eggs of Plaice be developed into Young Fish within the Skaw? II. On the Young Stages of the genus *Zeugopterus.* (With one Plate). III. Can we enter into Competition with the Foreign Steam-trawlers in our Seas outside the Danish Territorial Limit. 1902 and 1903. 33 pp.

XIII. *A. Otterstrøm:* Eggs and Young of Fishes in the Danish Waters. (Investigations during 1904 and earlier years.) 1903 and 1904. 85 pp.

XIV. I. *C. G. Joh. Petersen:* The Influence of Light on the Migrations of the Eel. II. *K. I. Gemzøe:* Age and Rate of Growth of the Eel. 1906. 39 pp.

XV. *Idem:* I. First Report on the Oysters and Oyster Fisheries in the Lim Fjord. (70 pp.) 1908.

XVI. *C. H. Ostenfeld:* On the Ecology and Distribution of the Grass Wrack (*Zostera marina*) in Danish Waters. With 9 figures. 1908. 62 pp.

XVII. *C. G. Joh. Petersen:* II. Second Report on the Oyster and Oyster Fisheries in the Lim Fjord. 1908. (24 pp).

XVIII. *C. G. Joh. Petersen:* I. The Yield of the Limfjord fisheries in recent years and the transplantation of Plaice in 1908. With 6 tables and 1 Chart. II. Biological investigations on the stock of Plaice in the Limfjord. With 3 Tables. III. The Yield of the Prawn fishery from 1885—1907 and its improvement by means of protection. With 3 Tables. 25 pp. 1909.

XIX. *Idem:* Some Experiments on the Possibility of combating the harmful Animals of the Fisheries, especially the Whelks in the Limfjord. 20 pp. 1911.

XX. *C. G. Joh. Petersen* og *P. Boysen Jensen:* Valuation of the Sea. I. Animal Life of the Sea-Bottom, its food and quantity. With 6 Tables, 3 Charts and 6 Plates. 81 pp. 1911.

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*) The figures in ( ) refer to the "Fiskeri-Beretning" for the years quoted.

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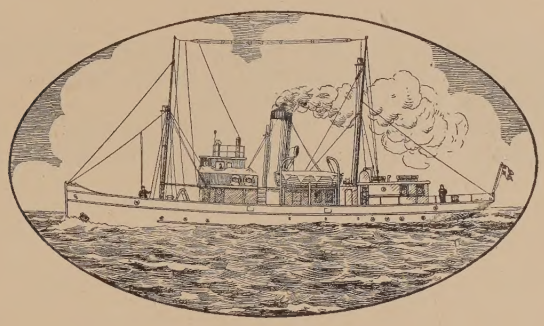

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On *Colpomenia peregrina* Sauv. and its Occurrence in Danish Waters.

By

SØREN LUND

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Introduction.

When carrying out some investigations for the Danish Biological Station in the Nissum Broad in the Limfjord in October, 1939, I had the opportunity of studying which species of seaweed had been washed ashore on the shoal N. E. of the entrance to Lem Vig. I have previously (1940, p. 180) made a short mention of this shallow and of the principal species found during the visit. By far the most plants belonged to *Fucus serratus*, which was mostly growing on small stones and shells. However, the most interesting species was undoubtedly the phaeophyceous alga *Dictyota dichotoma*, which i. a. was growing on *Fucus* and had not formerly been found at the Danish coasts, and concerning which it was established with certainty that its immigration was of recent date.

On a later examination of the material of *Fucus* plants, however, it turned out to contain another species that had not hitherto been observed in Danish waters, viz. *Colpomenia peregrina* Sauv. or *Colpomenia sinuosa* var. *peregrina* Sauv. This species, which is also a phaeophyceous alga, has a vesicular thallus. The specimens observed were growing on *Fucus serratus* and occurred rather abundantly.

Colpomenia peregrina is a very interesting species from a phytogeographical point of view because of its recent immigration into the European coastal waters of the Atlantic where it was observed shortly after the beginning of this century. After its discovery here it has been spreading rapidly, and in many localities it now plays a prominent part in the composition of the vegetation, for instance at the English and French coasts of the Channel, where it is mostly growing on many different algae, but also directly on the rocks. It is found in sheltered localities and is growing gregariously in the water of cavities and basins of the rocks (the pools) and on the rocky shore in the lower part of or a little below the tidal zone. The finding of the species in the Nissum Broad seems to indicate that it is still spreading and shows that it has now extended its range of distribution to the eastern part of the North Sea.

But also from an economic point of view the species has formerly been of considerable interest because at some time it caused vast devastations in the oyster cultures at the coasts of Brittany.

The following pages first contain a closer mention of the facts just described, after which an account will be given of the immigration of the species into Europe together with a brief statement of the available information on its structure and history of development and its occurrence at various seasons of the year. Finally, a comment will be made on the Danish plants and their conditions of living.

1. Devastations in oyster cultures of France.

The devastating effects of the species on the oyster cultures arose from the fact that it was often growing on oyster-shells and under certain conditions was able to rise to the surface of the water, at the same time raising the shells with the oyster provided that their weight was not too great. At the surface the plants with the shells were rapidly carried away by wind and current. In this way large amounts of young oysters might be lost. Sometimes the growers of oyster tried to enclose the oyster-beds with nets thus attempting to prevent the oysters that had been raised to the surface from drifting away.

According to Sauvageau (1906, p. 1) the rising power of *Colpomenia* is due to the fact that fissures occur in the thallus of the lower part of the plant. At ebb-tide, when the plants were laid bare, the water ran out of the thallus, and air entered instead of it. When the water began to rise again, it entered into the plant from below, so that the air could not escape. On account of this the plant was often lifted by the tide, either detaching itself from the shell on which it was living or carrying along the

shell if it was not too heavy. On account of this "plundering" power the alga was in France given the striking name of "oyster thief" ("voleuse d'Huîtres").

No effective means existed against the thalli of *Colpomenia*—the "ballons" as they were mostly termed by the French growers of oyster. According to Fabre-Domergue (1906, p. 1224) some effect had been produced by sweeping the oyster cultures by means of thorny fagots, so that the "ballons" were torn to pieces.

An interesting example of a way in which nature herself within limited areas joined in the fighting down of the *Colpomenia* is given by Sauvageau (1908) from Vannes in the Morbihan Bay on the south coast of Brittany. After a vigorous attack in 1906 the species again appeared in the oyster cultures in the following spring. In certain localities, however, there turned up a chlorophyceous alga, *Enteromorpha clathrata*, which was growing partly on the oyster shells, partly on the sea floor. This alga, which attained a length of up to 30 cm., occurred in such quantities, that it practically choked the *Colpomenia*, thus protecting the oyster cultures against the devastating effects of the latter. The extinction was so effective, that specimens of *Colpomenia* were hardly found in these localities during the following year.

The harmful effects of *Colpomenia* in the oyster cultures at some time caused no small anxiety among the French growers of oyster, especially in 1906 when the vegetations were very vigorous and great damage was done at Vannes. Time has shown, however, that it did not come to cause the devastating effect on the oyster stock which was feared to begin with.

2. Account of immigration into Europe.

The first information on the occurrence of a *Colpomenia* at the European coast of the Atlantic N. of Cadiz in Spain came from France and was given by Fabre-Domergue in the report just mentioned (1906) where it is said to occur at Vannes by the end of 1905. However, the immigration has taken place earlier, for according to Sauvageau (1908, p. 752) it turned out later on that it had been growing in the oyster cultures of this locality for several years, though not in so large quantities, that the attention of the oyster growers was called to its presence. It was the attack of 1905 that brought about the detection of the species.

During the following years a number of French scientists published a series of information on the appearing of the species in other localities. A synopsis of the literature concerning this topic was given by Mme Lemoine (1912, p. 37).

It appears from the literature that the species was found in several localities of the Channel and the coasts of Brittany nearly at the same time (1905—07), so that it is not possible to determine its first place of occurrence (fig. 1). As some of the first French find-spots besides Vannes may be mentioned Belle Île and Quiberon in Brittany, various localities near Cherbourg, Saint Vaast and Wimereux on the strait of Calais (where it was only found to have been washed ashore, attached to a piece of wood).

During the following years it was observed along the west coast of France (Croisic, Île d'Oléron, Île d'Yeu) down to Guéthary in the Gulf of Gascogne. In the locality last mentioned it was found for the first time in March, 1911 (Sauvageau 1912, p. 479). The finding at Guéthary was interesting because here the time of immigration could be established (the end of 1910), for in spite of several careful examinations Sauvageau failed to find it earlier in 1910.

At the English coasts the species, according to Cotton (1908 a, p. 82), was found for the first time in 1907, when it was observed to occur in some few places at the Channel (Torquay in Devon and Swanage in Dorset). According to the same author (1911, p. 156), however, it turned out later on that it had been found at the Scilly Islands already in 1905 and at Fowey and West Looe in Cornwall in 1906. Regarding the distribution of the species in the Channel in 1911 Cotton supposes that on the English side it occurs throughout the area between Lands End and Poole Harbour while on the French side the eastern limit is put at the neighbourhood of Cherbourg, not mentioning the few specimens washed ashore at Wimereux (1911, pp. 153, 157).

Since then there has been a further spreading of the species: van Goor (1923, p. 79) reports its occurrence at the island of Terschelling off the Dutch coast where in 1921 it was found partly washed ashore in large quantities, partly attached to *Fucus*. In England it has spread to the Isle of Man in the northern part of the Irish Sea where it was seen occasionally about 1926 (Knight and Parke 1931, p. 41). During the following five years it spread

Figure 1. Map of the coasts of western Europe with some of the first find-spots of *Colpomenia peregrina* in various areas together with other localities mentioned in the text. The years denote the time of the first finds in the localities in question.

rapidly in this locality. It also occurs at the Irish coasts: Kenneth Rees (1935, pp. 108—09, 114) reports it from Lough Ine in the southwesternmost regions. Strange to say, Mrs. Newton does not seem to admit the species in her well-known "Handbook of the British Seaweeds" (1931). Up to 1939 the northernmost find-spot in Europe is apparently the shoal at Lem Vig in the Nissum Broad of the Limfjord.

There is no doubt that the immigration of *Colpomenia peregrina* into this country through the Thyborøn Kanal is of recent date. It is true that the exact date cannot be fixed, but we may take it for granted that it occurred after July 1920,

when, judging by his posthumous journals, the late Professor Rosenvinge visited the Limfjord for the last time. On this occasion dredgings were made i. a. on the shoal at Lem Vig without finding any *Colpomenia*.

Of course the occurrence of the species in the Limfjord is not necessarily the result of a natural immigration, however likely it would seem from the map Figure 1, for we cannot exclude the possibility that it has been carried into this water. Both the flora and the fauna of the sea show several instances of a species having been carried into a marine area where it was previously unknown.

An instance of this kind from the marine fauna is the so-called slipper limpet (*Crepidula fornicata*), a species that originates from the northeastern part of North America, but was carried to England at the end of the last century with American oysters, on the shells of which it was living. Since that time it has spread, not only to the coasts of Holland and Belgium, but in 1934 it was also observed in the Nissum Broad, into which water it has most probably been carried with Dutch oyster fry, which in the years immediately after 1930 were imported to this locality from Ooster Schelde (Spärck, 1935).

Whether or not *Colpomenia* is found in Ooster Schelde is unknown to the author, but it seems very likely if we look at its distribution along the Channel and at Terschelling. Accordingly, there seems to be any reason to suppose that *Colpomenia* has in fact been carried to the Limfjord with Dutch oyster fry in the beginning of the thirties in the same way as the slipper limpet. The idea of an importation of the species into the Limfjord as against the theory of a natural immigration is perhaps also supported by the fact that it has not been stated to occur at the island of Heligoland.

But no matter how the alga has arrived at the Nissum Broad, it is, however, a fact that the Limfjord belongs to its natural habitat. If it has not been carried to this water with oysters, it would therefore undoubtedly have spread spontaneously to the area sooner or later. According to Sauvageau (1927, p. 320) it must be expected to spread as far as the Shetlands or the Faroes.

For rather a long time the immigrating *Colpomenia* was supposed to be the same species as that occurring in the Mediterranean, *C. sinuosa*, which shows a cosmopolitan distribution in tropic and temperate seas. However, it was rather strange why this species, which at the coasts of the Atlantic had never been found farther northwards than at Cadiz in Spain (abt. Lat. 36½° N.), should suddenly appear in the Channel zone and at Brittany, spreading there so rapidly. In the vigorous growth of the species in this place French authors thought to find an effect of the Gulf Stream though it was a remarkable fact that the species had not been observed to occur at the coasts of Portugal.

In his later investigations, however, Sauvageau (1927) has pointed to the probability that the immigrating species, which so far had been termed *C. sinuosa*, did not correspond with the species of the Mediterranean, from which it deviated in several respects, both in consistency, shape and thickness of the thallus. Differences are also found in the sori and the length of the plurilocular sporangia. Sauvageau (l. c., p. 321) therefore distinguishes it from *C. sinuosa* as a separate variety, var. *peregrina*, or even as a separate species, *C. peregrina*.

The species, however, is very much like a *Colpomenia* form at the North American coast of the Pacific, where *Colpomenia* is found as far northwards as the Yakutat Bay in Alaska (Lat. 59°33′ N.). Sauvageau considers it probable that the immigrating species may originate from a cold area like this, or perhaps from an area a little more to the south on the Pacific coast of North America.

The rapid naturalisation of the species to the comparatively cold water of the Channel zone is in favour of this opinion, and so is the fact that the growth of the species is not so vigorous and that the species occurs less frequently in the warmer Gulf of Gascogne as in the Channel. Finally, it has turned out that the temperature of the water is more favourable to the development of the species in winter and spring than in summer.

3. Structure and development of the plant.

As said above, the thallus has a vesicular thallus. As a rule it is of a regular round and smooth, more rarely of a bulging and folded shape. At the base it tapers off to a narrow fastening part. The colour is yellowish brown or somewhat greenish. The size is rather variable and is often stated to correspond to the size of a tennis ball, an egg or a clenched fist. The dimensions, however, may be much larger: Cotton (1911, p. 155) reports that the English plants show a diameter of up to 12 cm., and Sauvageau (1927, p. 325) even says that according to

Corbière the French specimens from Cherbourg may attain a diameter of up to 30—35 cm.

Sauvageau (1927) has made a careful examination of the species and compared it to the form of the Mediterranean. The following description of the structure of the thallus is principally based on the work of this investigator.

The thallus is 140—280 μ thick, flexible, not brittle as in the Mediterranean form. On the outside it consists of small, polygonal cells, each of which contains a disc-shaped chromatophore with a pyrenoid; inside, of 3—4 layers of large, nearly colourless cells, which decrease in size in an outward direction (cp. Cotton 1908 b, fig. 2; Killian & Werner 1926, fig. 14).

Hairs with a basal growing zone occur in bundles dispersed over the thallus. The hairs do not issue from the surface, but come out from deeper cells as shown by Sauvageau (l. c., fig. 2 C—D).

Of fructifying organs only plurilocular sporangia are known. They occur in sori of irregular size on the part of the surface of the thallus that is turned towards the substratum; unlike in the Mediterranean form they here seem to develop independently of the groups of hair. When the individual sori reach one another in their growth, the fructifying parts may attain a considerable size (several cm.^{2}), thus gradually spreading to the higher parts of the surface of the thallus. The plurilocular sporangia are cylindrical; they are said to be only half as high as in the Mediterranean form, where they measure 40—50 μ.

The plurilocular sporangia are accompanied by unicellular, cylindrical or clavate paraphyses, occurring in variable numbers. In living plants (and to some degree in material preserved in alcohol) the paraphyses are refractive and nearly colourless, but in dried material they show a brown, homogeneous content. The plurilocular sporangia have been pictured by Cotton (1908 b, fig. 2), the figure showing a section through a fructifying thallus. They are also seen in Sauvageau (l. c., fig. 2 E), where they are viewed from above.

The zoospores from the plurilocular sporangia were examined by Sauvageau (1926, p. 833 and 1927, p. 335) in an individual from Guéthary. They did not copulate, but grew out directly into a monosiphonous, branched or unbranched protonema, on which, after several cell divisions in certain spots, there was a gradual development of one or several new *Colpomenia* thalli, which were solid to begin with. On the old protonema there grew out plurilocular sporangia, the zoospores of which gave rise to a protonema of the second generation. The latter was highly branched, but did not produce sporangia, not even after several months.

The development in nature of the younger stages was studied by Killian & Werner (1926, p. 90), who made their observations near Roscoff at the coast of the Channel. The youngest stages consisted of creeping filaments, on which vertical shoots developed. During several divisions of cells, particular of a radial kind, these shoots already at an early stage formed a tiny round and solid thallus. From the lower cells there was a development of rhizoids. Gradually a marked difference arose between the inner and the outer cells: the former were growing in size while the latter, owing to several divisions continued to be small. During the further growth the cavity of the thallus came into existence.

4. Variations in the seasonal occurrence at the coasts of England and France.

The species is not equally prominent throughout the year. In 1908—10 Cotton (1911, p. 154) made investigations on its occurrence at different seasons near Weymouth on the English coast of the Channel. In this locality the species occurs both in the pools and on the rocks of the coast, here growing both in the lower part of the tidal zone and in the upper part of the sub-littoral region immediately below the low water mark. It is principally growing on other algae, but is also found directly on the rocks. The most vigorous development is found in the pools, where it is growing on many different algae, for instance *Halopithys*, *Cystoseira*, *Fucus serratus*, *Ceramium* and *Polysiphonia*.

It appears from Cotton's investigations that at Weymouth the species is principally a winter plant, which generally begins to grow in autumn and disappears in late spring or early summer, though individual plants may also be found in summer. At the beginning af September it consisted of small, round thalli, measuring only 1—2 mm. in diameter. By the end of the month the plants were up to 1 cm. or more in diameter and now occurred in larger numbers. During the next two months the growth was rapid, and by the end of November many of the plants had a diameter of 1½—2 inches. In

January there was a small decrease of the vegetations, a fact that i. a. is put down to stormy weather, which may have exercised a reducing effect on the stock. In March—April the species was very conspicuous, but it began to disappear already at the end of April. The period of fructification generally lasted from November to April.

Also at the French coasts there is a certain variation of occurrence at different seasons of the year (Sauvageau 1927, p. 321); here, too, the species is nearly absent in summer. Near Roscoff on the coast of the Channel its disappearance and reappearance is supposed to agree with conditions at Weymouth. At Guéthary in the Gulf of Gascogne it attained its maximum size and frequency in February—April, at Cherbourg in May.

In contrast with the observations from the coasts of the Channel Knight & Parke (1931, p. 41) say that at the Isle of Man it is a frequent plant in the summer flora of the littoral zone. It will therefore be of interest to follow the species at different seasons in the Limfjord.

5. Description of Danish plants from the Limfjord.

As mentioned above the Danish plants from the shoal at Lem Vig in the Nissum Broad were growing on *Fucus serratus*, being rather numerous on both sides of the thallus. They were all quite small, ranging between a few mm. and fully 1 cm. in diameter. Most of them were of the size of a pea, the largest of them being as big as a hazel-nut. Generally, two or more specimens were growing together, forming small colonies; single individuals were not so frequent. In the latter case they were of a comparatively regular, globular shape, judging by some few specimens preserved in alcohol. When several specimens were growing together, however, they seemed to be liable to accrete at the points of contact, thus getting a somewhat more irregular shape. The colour of the dried plants was greenish or brownish.

On fig. 2 is seen a piece of the thallus of *Fucus serratus* in natural size with epiphytic *Colpomenia* plants, showing their way of growing. The drawing is based on soaked herbarium material.

The thallus is smooth and flexible, in the largest plants a little more than 200 μ thick. In an anatomical respect it is divided into two parts. The outer layer, the cortex, consists of 1 (or 2) layers of small, mostly 4- to 6-edged cells, each containing a small, disc-shaped chromatophore with a distinct, refractive pyrenoid. The chromatophore, which is mostly roundish, generally seems to take up only a comparatively small part of the cell. The inner part of the thallus consists of 3—4 layers of large, colourless, more or less roundish cells. The cells of the inner layer are the largest, the size gradually decreasing in an outward direction.

Hairs with a basal growing zone are present in plenty. They occur in bundles, sitting in cryptostomata in exactly the same way as in Sauvageau's fig. 2 C —D (1927).

Most of the specimens in hand seem to be sterile, which is undoubtedly due to the small size of the plants. In some of them, however, small spots with plurilocular sporangia and paraphyses were observed on the lower part of the thallus. The plurilocular sporangia are cylindrical and generally contain 2 series of compartments, each of these containing 1 spore. They are mostly a little shorter than or of the same length as the paraphyses.

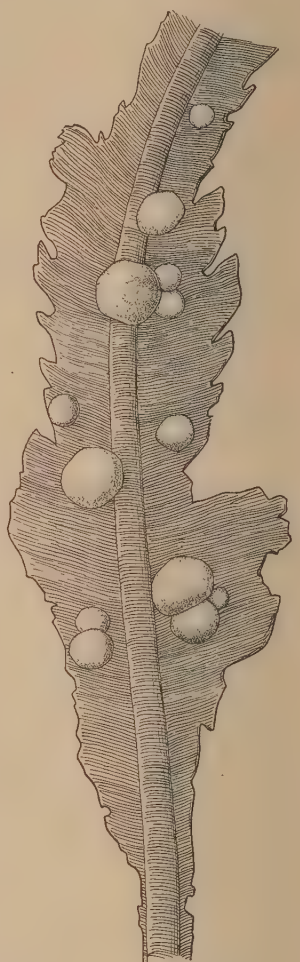

Figure 2. *Colpomenia peregrina*. Plants in natural size growing on *Fucus serratus*. The drawing is based on soaked herbarium material. —The shoal at Lem Vig 18-X-39.
Ingeb. Frederiksen del.

In one small, dried specimen, which was conspicuous by its dark brown colour, nearly all the plurilocular sporangia seemed to have been emptied, so that only the paraphyses (and the bundles of hair) projected above the surface of the thallus. The dark colour of the plant must undoubtedly be explained by the fact that practically all the very numerous paraphyses showed a plentiful, dark-brown contents. Otherwise, the paraphyses of this plant were characteri-

stic by being larger than in the other individuals. They were frequently more than 40 μ long, some of them even more than 50 μ.

Nearly all the specimens in hand were without epiphytes, though in rare cases some few young phaeophyceous algae have been observed: *Giraudia sphacelarioides* and *Ectocarpus paradoxus*, both with plurilocular sporangia.

In order to get an impression of the occurrence of *Colpomenia* in the Nissum Broad at different seasons of the year I made, at the instigation of Dr. H. Blegvad, Director of the Danish Biological Station, three excursions to the shoal at Lem Vig in 1942: on April, 21st, on July, 22nd, and on December, 27th. However, I did not manage to find one individual of the species though minute searches for the species were made on all three occasions: each time a large number of *Fucus serratus* and other algae were examined together with a lot of stones and shells. Most likely, therefore, the species was no longer found in this locality. Of course it was not out of the question that it might be found in other—perhaps more protected—localities of the Limfjord, but I was inclined to believe that the severe winters 1940—42 might have caused a total extinction of the species.

During the preparation of the present work, however, Tyge Christensen, Stud. mag., most kindly handed over to me some specimens from the Limfjord of a vesicular alga, which proved to belong to *Colpomenia peregrina*. This material originates partly from 2 localities of the Sallingsund: the ferry Pinen on the Salling side and Ørodde near Nykøbing Mors, where the species was collected on 2. August, 1940 and 10. August, 1940, respectively, partly from the Nissum Broad near Oddesund, where it was found on 25. August, 1942. In all three localities the plants had been washed ashore.

It appears from this that already in 1940 the species had advanced some distance eastwards into the Limfjord. The time of its arrival at Sallingsund cannot be given precisely, but it must have been after 1920, possibly in the beginning of the thirties (cp. p. 8). The findings here in 1940 and on the shoal in the Nissum Broad in 1939 only mark the first find-spots in the Limfjord and of course need not denote the time when the species immigrated into the said areas. Most likely, however, it has arrived at Sallingsund shortly after having entered the Nissum Broad. Fructifying specimens that have risen to the surface of the water may rapidly be carried far away by current and wind, thus spreading the species over vast areas. As will appear from the find at Oddesund in 1942, the alga has survived the three severe winters, and so there is reason to believe that it may now be common both in the western and the central part of the Limfjord.

The new material, which includes both dried plants and individuals in alcohol, shows a far more advanced development than my own material from the shoal at Lem Vig, the plants ranging between

Figure 3. *Colpomenia peregrina.* Plant in natural size immediately after being raised to the surface of the water by inflated air. At the fastening point a small piece of the host-plant, *Polysiphonia nigrescens*.—Oddesund 25-VIII-42.—Ingeb. Frederiksen del.

3 and 8 cm. in diameter. The largest specimens originate from Ørodde, where they had drifted to the beach in large numbers immediately N. of the area of the Oyster Company.

The specimens are of a comparatively regular, round shape with a rather broad base tapering off into a narrow fastening part. Most likely all of them have been growing separately. The plant pictured in fig. 3, which had a diameter of about 3 cm., was attached to *Polysiphonia nigrescens*. The shape may be studied more closely when the plants preserved in alcohol are transferred into water and are inflated by means of a pipette, after which they will at once rise to the surface as shown in fig. 3. The degree to which the plant will project above the water depends on the quantity of air contained in it.

It remains to be said that the plants agree very well with my own individuals from the shoal at Lem Vig and with the descriptions of the literature. The dried individuals are of an olive green or olive brown colour. The thickness of the thallus amounts to well over 200 μ. When viewed from above the

surface cells are 4- to 6-edged, each with a disc-shaped chromatophore containing a pyrenoid (fig. 4 A). As a rule the flat of the chromatophore is turned towards the outer wall, though in some cases it is bent downwards into the cell. The bundles of hairs occur in cryptostomata and are issuing from deeper cells in the thallus (fig. 4 B, D). The hairs are 10—13 μ thick in the growing zone. Sometimes the lowest cell of the hair is rather long and may taper off at the base.

No doubt most of the specimens are sterile, but in some of them plurilocular sporangia occur abundantly. The fructifying parts, which are a little darker than the rest of the thallus, sometimes show a considerable expansion owing to the accretion of the individual sori. Apparently, however, this accretion is not always complete, small light spots always occurring between; this no doubt frequently means that the thallus is sterile in these places, but it may be, too, that the plurilocular sporangia are still very young here or have already been emptied, therefore showing a lighter colour than the rest of the sporangia (cp. Sauvageau 1927, p. 317).

The plurilocular sporangia are cylindrical and generally contain 2 rows of compartments (fig. 4 C—D). The number of floors runs to 3—6, the most frequent number being 4 or 5. The length of the plurilocular sporangia ranges between 20 and 35 μ, about 30 μ being the length most frequently observed.

In other words the length is a little greater than stated by Sauvageau (1927, p. 317), according to whom, as mentioned above, they are only half as long as in *C. sinuosa*, where they are about 40—50 μ. In Cotton's figure, however, (1908 b, fig. 2) they seem to have been even longer, all the plurilocular sporangia figured with one exception containing a total of 7 floors.

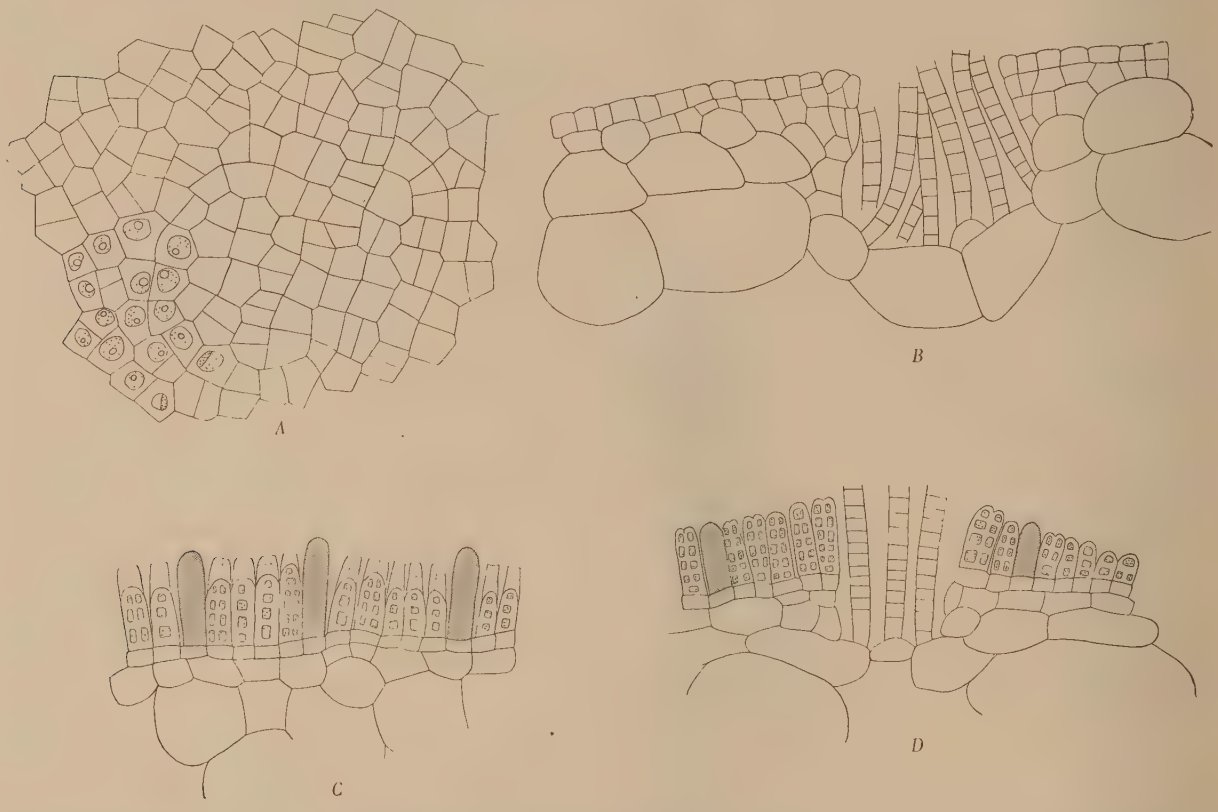

Figure 4. *Colpomenia peregrina*. A: Part of the surface of the thallus viewed from above. In some of the cells is seen the chromatophore with the pyrenoid. B: Transverse section of sterile thallus with a cryptostoma. C—D: Transverse section of fructifying thallus showing plurilocular sporangia, paraphyses and a cryptostoma.—A, C—D: Oddesund 25-VIII-42; B: Ørodde 10-VIII-40. A: × 525; B—D: × 355.

When the plurilocular sporangia have been emptied, they may, as in so many other phaeophyceous algae, be penetrated by new plurilocular sporangia. Fig. 4 C shows such "compensation sporangia", above which are seen the upper part of the remains of the old, emptied plurilocular sporangia.

The paraphyses are present in greatly variable numbers. They are either of the same length as or project more or less above the plurilocular sporangia (fig. 4 C), their length ranging between 20 and 45 μ.

Immediately before the termination of the present paper I received from Mr. Tyge Christensen some further specimens of *Colpomenia* from the Limfjord. The fresh plants had been collected in the summer of 1943, and they originate partly from the northern part of the Sallingsund, partly from Hanklit in the Thisted Broad.

Most of the specimens from the first mentioned place had been collected in the immediate vicinity of Ørodde—the finding place of 1940. They were remarkable for their being attached on their growing place—and being on the whole the first Danish specimens that have been collected for certain in the growing place. They were found on a breakwater at depths from a little below the surface to fully 1 m. and were present in plenty. Like the specimens found at the coasts of France and England they were growing partly epiphytically on other algae, partly directly on stones. The hosts were primarily *Polysiphonia nigrescens*, further *Fucus serratus*, *Fucus vesiculosus*, and *Scytosiphon Lomentaria*. The specimens examined were rather small, measuring between well over 1 mm. and barely 2.5 cm. in diameter.

Besides the plants from Ørodde the fresh material from the Sallingsund included a couple of smaller specimens from the vicinity of the old ferry pier at Sallingsund on the Mors side (opposite the ferry Pinen). They were growing on *Fucus* that had been washed ashore.

The material from Hanklit in the Thisted Broad consists of 2 plants, about 3—3.5 cm. in diameter. Both of these, too, had drifted ashore. One of them was fixed to a fragment of *Polysiphonia nigrescens*.

Thus *Colpomenia* has been collected within a total of 3 areas of the Limfjord: the Nissum Broad, the Sallingsund, and the Thisted Broad. As mentioned however, a sure instance of attachment in the growing place was observed only at Ørodde in the Sallingsund. This locality is situated on Lat. 56°47′ N. and is the northernmost growing place of the species hitherto found in Europe. Hanklit in the Thisted Broad, situated a short way further to the north on Lat. 56°54′ N., is the northernmost place at which the species has been found to have drifted ashore.

6. Hydrographical conditions in the Nissum Broad and Sallingsund.

The occurrence of *Colpomenia peregrina* in the Limfjord, which in a hydrographical respect is characterized by a rapid and extensive heating in summer and cooling in winter, shows that the species is able to sustain great fluctuations in the temperature of the water and freezing up of the water for shorter or longer periods. Furthermore, it is able to thrive at salinities down to no more than 26 per mille.

By way of further illustrating the hydrographical conditions in the Nissum Broad and Sallingsund I have in fig. 5 reproduced fig. 3 from Jensen's paper on the hydrography of the Limfjord (1927). The figure gives a graphic representation of the average annual variation of the temperature and salinity of the surface water at Oddesund in the eastern part of the Nissum Broad and at Glyngøre in Sallingsund (and at Aalborg, which in this connexion is without interest). The graphs are based on the daily observations made by the Meteorological Institute in the localities in question and rerorded in the Nautical-Meteorological Annual. At Oddesund observations were made from 1898 to 1927, so that the graphs from this place express the means for 30 years, but at Glyngøre the observations cover a shorter period only, from June, 1910 to December 1913. However, the monthly means of this period from the latter locality have been corrected so as to apply to the same series of years as at Oddesund.

It appears from the temperature graph for Oddesund that the surface water in this place is coldest in February, when the temperature sinks to 1.0°, and warmest in July when the temperature rises to 16.6°, the difference between the coldest and warmest month thus amounting to 15.6°. In Sallingsund conditions are much the same, only that the water here is a little colder in February (0.7°) and a little warmer in July (17.2°), the difference between the temperatures of February and July thus being 16.5°.

If we look at the variations of temperature within the individual years, there are of course in some cases greater differences between the coldest and the warmest months: from recent years the Nautical-Meteorological Annual reports that at Oddesund the difference was 20.2° in 1937 (average —0.6° for February, 19.6° for August, which was the warmest month of this year). In 1941, when the Nissum Broad was covered with ice in February, the difference was even greater, the ice on an average appearing to be about —1.5° to —1.8°, and the mean temperature of July being 19.3°.

If we finally look at the measurements on the coldest and warmest day within the same year, the difference mostly rises to more than 20° (examined during the years after 1930). In 1937 and 1941 it even amounted to about 24°. In both years there was ice in February; in 1937 the highest temperature measured was 22.6° (7. August), in 1941 22.4° (14. July).

As to the duration of the ice periods of the three severe winters it may be stated that in 1940 the Nissum Broad was covered with ice for about two months, from a little after the middle of January into the month of March besides for shorter periods later on; in 1941 for about 2½ months, from the beginning of January to far into March; and in 1942 for nearly 3 months, from about the middle of January into the month of April. It is true that the ice periods were unusually long in these three winters, but the conditions of these years should be emphasized because, as mentioned, *Colpomenia* was present during this period and survived.

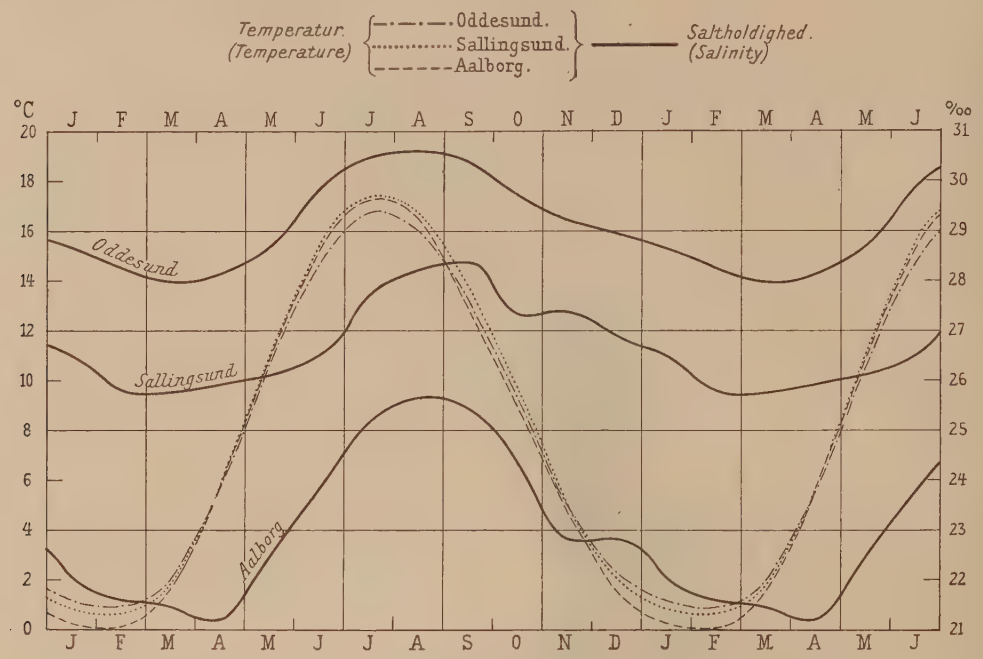

Figure 5. Yearly range of temperature and salinity of the surface water at Oddesund, Sallingsund and Aalborg. From Jensen, 1928.

Concerning the salinity of the surface water it appears from the graphs that the annual variation is but small (about 2.5 ‰). At Oddesund the minimum occurs in March—April with about 28 ‰, the maximum in August with barely 31 ‰. In Sallingsund the salinity is a few per mille lower: here the minimum occurs in February—March, amounting to about 26 ‰; the maximum in September is about 28.5 ‰.

By the end of this paper it will be natural to say a few words of the possible danger to which the Danish oyster cultivation is exposed from this new alga. As will be known, the relaying beds of

oyster are found in the Nissum Broad while the natural beds are mainly situated further eastwards, for instance in the Sallingsund. Both the relaying beds and the natural beds are thus found in localities where *Colpomenia* has been collected.

However, it may be established at once that a danger does not at any rate exist in connexion with the tide, which in the Limfjord is very slight, so that a laying bare of the oyster beds during ebb tide as at the coasts of Brittany cannot take place. Plants of *Colpomenia* that might be supposed to grow on oyster shells therefore will not be able to act as floats.

However, it is quite another question whether *Colpomenia* during its CO_2-assimilation may be supposed to be able to disengage so much oxygen in its hollow thallus, that it is raised to the surface on this account. This possibility cannot perhaps be pre-eliminated, but there are undoubtedly no great chances of its affecting the growing of oyster because at any rate the relaying beds mostly occur in somewhat deeper water (4—6 m.) than that in which the *Colpomenia* may be expected to be found.—In other words there seems to be no reason to believe that the *Colpomenia* will affect the oyster growing of this country in a harmful way.

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The Liberation of Salmon and Trout Fry in Denmark.

By

KNUD LARSEN

Salmon and trout fry have been liberated in Danish water-courses during a long series of years; hatchings were started already in 1858 and a hatching station was built at Viborg in 1865. But no fixed principles in the liberations of fry existed until recent years; when the close season for salmon and trout was dispensed with in order to procure fertilized roe, this i. a. was done on condition that the fry hatched were liberated within the area from which the motherfish originated, irrespective of the annual fluctuations in the amount of fry and without any exact knowledge of the quality of the water as a nursery area for the fry and the young fish. Liberations of fry with government grants by fishermen's associations and more or less filantropic societies for the advancement of fisheries were formerly carried out from the principle: the more fry, the better—a rather objectionable principle from our present knowledge, though it is still followed in some few localities.

Gradually the impression arose that we acted blindfold in the liberations of fry, and there were doubts whether the previous distribution of the grants for the liberations was the right one. In 1927, therefore, the fresh-water department of the Danish Biological Station made an examination of two streams of West Jutland (the Sneum Aa and the Kongeaa) for the purpose of making a rational plan of liberation. Apart from an examination of Brede Aa and Bovrup Bæk in 1932 the matter rested until 1934 on account of lack of personnel, but in the meantime the principles of the rational liberation of trout fry had been worked up and published[1]). After this the widest possible distribution of the fry is aimed at, pre-eminently to the areas of the streams that, on account of dammings, are barred to the sea trout naturally ascending; the density of the stock liberated is conditioned upon the character of the streams, which are classified according to the dimensions and conditions of bottom, vegetation, nourishment, etc., and due regard is paid to barrings (turbines, irrigations, pollutions). Under the same title but with various additions this first statement was printed as a pamphlet with German summary (Lyngby, 1935), and after the work with the plan of liberation for the river Gudenaa had been terminated, the same principles were published with special regard to the area of this stream[1]).

In 1934 the plans of liberation were taken up once more, and by now 38 such plans have been worked up including a quantity of 2,336,500 pieces of fry to be liberated annually (Table 1 and Figure 1). The old plans for the Sneum Aa and the Kongeaa were revised in 1934, and in 1939 they were drawn up in the same way as the more modern plans.

Originally the water-courses were visited on bicycle, but this procedure turned out to be too slow on account of the large number of requests for plans drawn up by the Biological Station, and in 1939 a motor-bicycle was used. In this way inspections were made at the Skive-Karup Aa (No. 15), the Vors Aa (No. 22) and the streams falling into the northern side of the Faxe Bugt (No. 35). However, the war put a sudden end to this and to the idea of working up plans of liberation for all trout streams of this country within a reasonable time.

At present we make it our business to work up plans of liberation for all such areas in which motherfish are being caught on dispensation from the close time regulations or where liberations are subsidized

[1]) C. V. Otterstrøm: Planmæssig Udsætning af Ørredyngel i Vandløb (Systematical liberation of trout fry in water-courses). Ferskvandsfiskeribladet, 31. Aarg. 1933. No. 2—3.

[1]) C. V. Otterstrøm: On Methodical Liberations of Salmon and Trout Fry in water-courses with Special Reference to the Gudenaa Area. Rep. Dan. Biol. Stat. XLII, 1937.

Table 1. List of the plans of liberation of salmon and trout fry (cp. Figure 1) worked up by the Danish Biological Station down to April 1., 1943.

No.	Area	Streams examined	Plan of liberation dated	No. of fry	No. of places of liberation	Draining area
1	Tværsted Aa and Flodbæk	1935	1936	5 200	6	
2	Ugerby Aa	1938	1938	72 000	114	
3	Storaa	1934	1935	83 600	106	
4	Streams between Storaa and Madum Aa	1934	1938	400	1	
5	Madum Aa	1934	1938	0	0	
6	Tim Aa	1934	1938	400	1	West coast of Jutland
7	Hover Aa, Heager Aa, Venner Aa	1936—37	1938	30 600	43	
8	Skjern Aa	1936—37	1938	175 400	188	
9	Varde Aa	1938	1939	123 200	125	
10	Sneum Aa	1927	1927	150 000	67	
11	Kongeaa	1927	1927	98 000	57	
12	Brede Aa	1932	1932	50 000	34	
13	Vidaa	1934	1935	107 000	76	
14	Outfalls into Kilen at Struer	1941	1941	14 200	10	
15	Skive-Karup Aa	1939	1939	89 500	83	
16	Trend Aa	1942	1943	42 000	19	
17	Halkjær Aa	1934	1935	17 000	19	The Limfjord
18	Binderup Aa	1941	1941	52 700	15	
19	Lindenborg Aa	1936	1937	56 000	52	
20	Knasborg Aa	1936	1937	5 900	7	
21	Elling Aa	1936	1937	23 800	55	
22	Vors Aa	1939	1940	56 500	79	
23	Outfalls into the Hobro-Mariager Fjord	1940	1941	104 500	63	
24	Gudenaa	1932—36	1936	393 000	386	
25	Grenaa, part.	1942	1943	48 800	28	East coast of Jutland
26	Aarhus Aa	1940	1941	8 600	7	
27	Kolding Aa	1938	1938	33 100	24	
28	Other outfalls into the Kolding Fjord	1940	1941	29 000	16	
29	Hoptrup-Genner area	1940	1941	29 000	15	
30	Outfalls into the Aabenraa Fjord	1940	1941	36 600	23	
31	Graasten area[1])	1940	1941	14 500	17	
32	Streams on Als	1940	1941	13 500	15	
33	Vindinge Aa	1942	1943	50 300	20	
34	Outfalls into the Præstø Fjord	1941	1941	27 600	14	
35	Outfalls on northern side of Faxe Bugt	1939	1940	9 100	5	
36	Outfalls on eastern and southern side of Roskilde Fjord	1941	1941	85 100	23	The islands
37	Outfalls on western side of Roskilde Fjord	1942	1943	1 600	3	
38	Streams on Bornholm	1941	1941	198 800	66	

[1]) Including plan of liberation for Bovrup Bæk of 1932 (examined 1932).

Figure 1. Areas for which liberations of salmon and trout fry have been planned (cp. Table 1).

by government grants. Such plans now exist for the streams in which generating stations are legally bound to put out fry; these are the Varde Aa (No. 9), the Gudenaa (No. 24) and the Kolding Aa including other streams falling into the Kolding Fjord (No. 27 and 28).

A plan of liberation now consists of the following sections:

1. An introduction containing an account of the main principles for the valuation of the watercourse, the total number of fry to be liberated, the number of the places of liberation, and information on pollutions, barrings, etc. met with during the examination of the stream.
2. A text commenting on the valuation of the individual areas of the stream and stating the number of fry to be liberated within the said area and the figures of the localities in which the fry should be liberated. In the older plans two figures are given for the amount of fry, a smaller figure (Scale I) if fry are liberated every year and a larger figure (Scale II) if liberations take place every second year only. But now this arrangement has been abandoned because it turned out that it tempted to use a larger number also in cases when fry were liberated every year, which involves the risk of a poor thriving of the fry on account of too small amounts of nourishment. Only Scale I is used now, the numbers of which may aptly be doubled if liberations take place every second year only.
3. A "scheme of liberation", a skeleton-like arrangement of the figures of the localities of liberation and the amount of fry to be liberated in the said locality (Table 2).
4. A set of maps (size 1 : 40,000 on hemp paper), on which the localities of liberation have been marked in red and supplied with number, and
5. a general map of the area of water for orientation and support in the working up of special lists of distribution, reports, etc. (Figs. 2 and 3).

If the possibilities for the descent of the young fish from a part of the stream otherwise suited are found to be too small, so that fry of salmon or sea trout should not be liberated here, the localities of liberation are marked down both on the special and the general maps but without numbers, and they are omitted in the scheme of liberation (the Onsild Aa and Hodal Bæk in Fig. 2, the Muleby Aa and Læsaa in Fig. 3).

Table 2. Scheme of liberation for outfalls into the Hobro-Mariager Fjord.

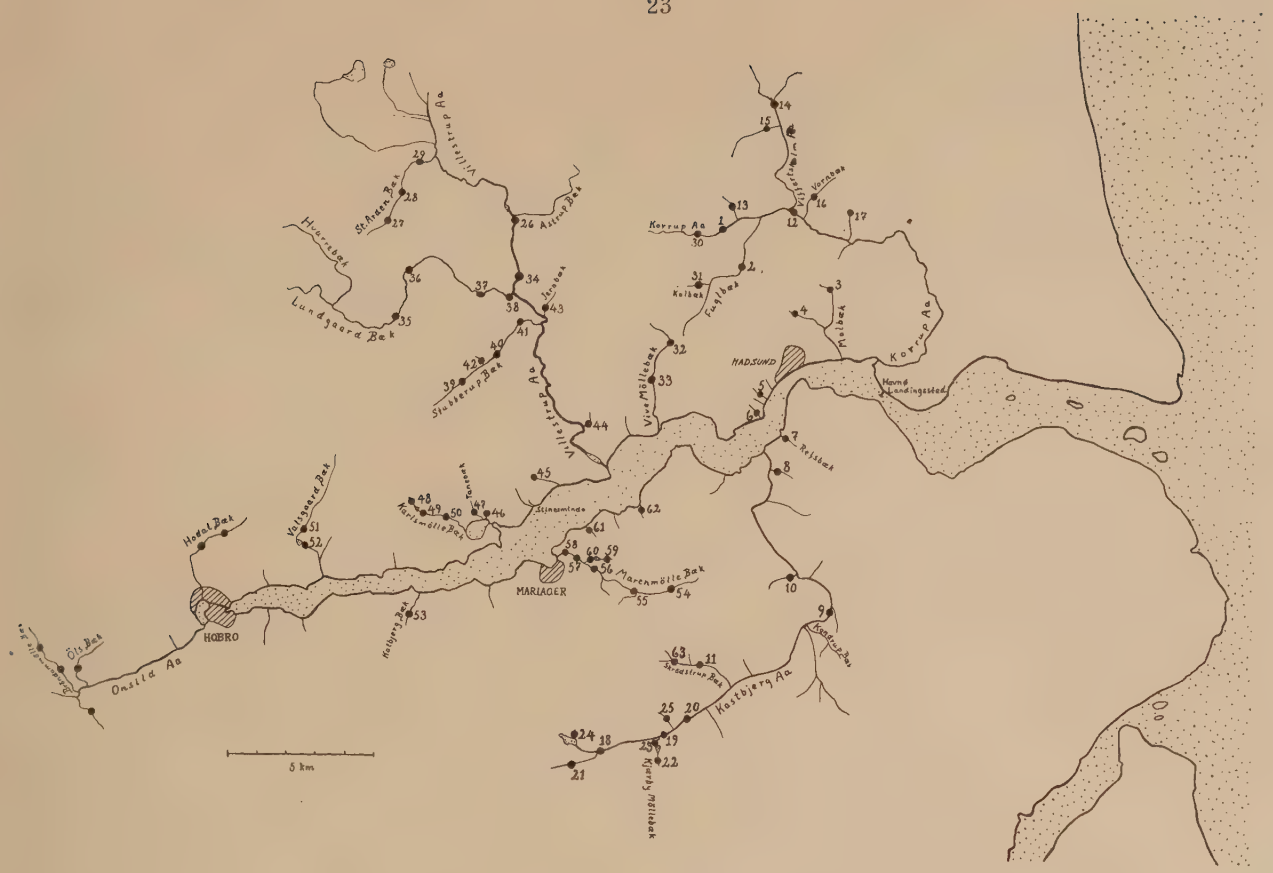
The places marked down with red and provided with a number on 5 of the accompanying 8 special maps may be used for the liberation of the following amounts of trout fry.

Locality No.	No. of fry	Locality No.	No. of fry	Locality No.	No. of fry
1	3 000	22	4 000	43	360
2	1 000	23	700	44	200
3	480	24	150	45	1 000
4	900	25	480	46	240
5	350	26	8 000	47	400
6	250	27	950	48	1 750
7	700	28	900	49	1 000
8	600	29	600	50	1 700
9	3 200	30	1 500	51	1 800
10	2 100	31	500	52	1 600
11	1 800	32	600	53	600
12	5 300	33	800	54	200
13	600	34	12 000	55	220
14	420	35	720	56	1 400
15	700	36	2 560	57	375
16	800	37	6 000	58	390
17	500	38	11 200	59	1 000
18	2 000	39	1 475	60	960
19	2 000	40	4 000	61	180
20	1 500	41	1 400	62	320
21	1 000	42	500	63	600

Instances of streams in which the said causes make it inadequate to stock large areas with fry of migratory fish are the Aarhus Aa, the Kolding Aa and the Alling Aa (tributary of the Gudenaa). The barring of the Aarhus Aa area covers the tributary Lyngbygaard Aa and consists of a turbine put up at the lower end of this tributary and not allowing the young trout to pass; at the same time the free water is emitted through an eel-trap, the bottom of which is raised above the surface of the back-water. The area thus barred was calculated for a liberation of 29,300 pieces of fry. In the water area of the Kolding Aa the Harte Generating Station in the same way bars most of the Vesternebel Aa and the whole Almind Aa where conditions otherwise would allow a liberation of 40,000 pieces of fry. As to the Alling Aa compare C. V. Otterstrøm 1937, p. 25 and Fig. 20. As a rule government grants are afforded only for liberation of fry of migratory fish, and so these grants can only be counted on for areas from which there is an unimpeded descent.

The liberations so far carried out have afforded certain experiences of a purely technical nature, which will be accounted for in the following.

For the work of liberation itself the special maps


HOBRO
MARIAGER
HADSUND
Korrup Aa
Vivet Møllebæk
Kastbjerg Aa
Omslid Aa
Lundgaard Bæk
Stubberup Bæk
Hedet Bæk
Kvistgaard Bæk
Mølleå
Dundale Aa
Tejn Aa
Kompedal
Bagaa
Mule by Aa
Tingsted Aa
Blyhobbe Aa
Lerbæk
Lerbæk
Lerbæk

and the scheme of liberation will suffice. If the liberation takes place within a smaller area, so that one motor-car is able to do all the transport, the liberation scheme of the plan may be used directly, but if several cars are used, each of them must have maps of the area to be stocked and a special list of distribution for the area. The person responsible for the liberation must work up such lists on the basis of the scheme before the liberation begins. In several localities it has proved useful to summom the different parties on the eve of the liberation in order to instruct them on the handling of the fry and to orientate them on the map, so that no time is wasted over this on the day of liberation. The necessary number of transport pails should also be procured in time and labels attached to them, on which the name of the driver and the amount of fry is written on the deliverance of the fry.

As transport vessels milk pails have turned out to be the best; they are easily placed on the floor of a motor-car, they are easy to handle if the water is to be changed, and the fry are easily seen in them and can be taken out without trouble. A common milk pail will take about 15,000 pieces of fry if they are not too old; if the yolk-sacs are gone, no more than 8—10,000 specimens should be conveyed in each pail. The fish should be kept under constant observation; if they come to the surface, it means lack of oxygen. A cooling of the water in the pails by means of ice has proved to have good effects.

At the place of liberation the most practical procedure is to take out the fry by means of a small catcher (for instance a coffee-filtering bag sewn to a ring of iron-wire, the lower edge of which is made flat) and to shift them to a smaller pail that can easily be carried along the stream. At intervals a small portion of fry is poured out until the contents of the pail have been distributed over so large an area as time will permit. A watering pot, from the spout of which the sieve has been removed, is even better for the distribution; during the pouring out the mouth of the spout should be put below the surface of the water, and the fry should be poured out in the direction of the current of the stream and not against it or crosswise.

The measuring of the right number of fry may be difficult, but an examination at the hatching station of the volume for instance of 200 pieces of fry in the small catcher will constitute the basis of a rather safe estimate.

During the war it has been difficult to distribute the trout fry so well as in the years when unlimited quantities of petrol were at disposal. We have been tempted to reduce the number of places of liberation, but if we do not simultaneously reduce the number of fry liberated in the same proportion, we run the risk of over-exploiting the nutritive power of the streams. By smaller streams the liberation tours could undoubtedly to a great extent be made on bicycle[1]), and we have seen that also larger areas of water (tributaries of the Gudenaa round Silkeborg) may be stocked in this way by a collaboration between the boy scouts organization and the fishermen's association.

[1]) John-B. Hahn: Udsætning af Ørredyngel (The Liberation of Trout Fry). Ferskvandsfiskeribladet, 41. Aarg., 1943, Nr. 4.

Turbines and Descending Salmon and Trout Smolts (and Eels): IV

By

C. V. OTTERSTRØM

Since 1930 the Danish Biological Station has made a number of experiments on turbines of various types and sizes in order to find out how great a danger these turbines present to the fish.

Reports on nine of these experiments were published in the Journal du Conseil international pour l'exploration de la mer (vols. VI, 1931, VII, 1932, and XI, 1936), the experiments on three turbines being described in each report. The same reports have appeared in Danish in the Sports-Fiskeren (1932, no. 1, 1932, no. 7, and 1936, no. 12), and the first has also been published in Italian, unfortunately disfigured by some strange errors, in the Bolletino di pesca, di piscicoltura e di idrobiologia (1932). Under present circumstances the above-mentioned periodical of the International Council is not published, hence the following report on the experiments made at Ribe Stampemølle (the stamp-mill of Ribe) and Holstebro Kraftstation (the power station of H.) is published here.

1. Ribe Stampemølle.

On the 16th of November 1940 some experiments were made in order to ascertain the effect a passage through the turbine found there would have on fish of different kinds and sizes. The experiments were actually occasioned by the transformation of Ribe Midtmølle (the middle mill of R.) taking place just then. Here there had hitherto been an old-fashioned water-wheel, but now a turbine (Fig. 1) was installed, of a type on which such experiments had never before been made. As there is already at the stamp-mill a turbine of the same type and size, the experiments made on the former turbine are valid for both.

On the turbines the following information obtained from De Smithske Jernstøberier og Maskinværksteder of Aalborg may be offered. The turbine for the stamp-mill was delivered in 1939 by the machine factory Lindholm, N. Sundby, but the cast iron parts being cast by the Smithske Jernstøberier, which on the 1st of September of that year took over the right of production of turbines of this type (Francis turbines of the Finshyttan system), and which amongst others have produced the turbine for Ribe Midtmølle corresponding in type and size.

The two turbines have runners (Fig. 2) with a diameter of 104—173 cm. and with 13 bucket vanes. The rotative speed is about 80 rotations a minute. At a mean head of about 1.75 m. the turbines develop 80 h. p., at 2.05, 100 h. p. The number of guide vanes is 20 (Fig. 1), their height 63 cm.; they are adjustable, and the maximum aperture between them is 15 cm.

The experiments were made in a similar way as on previous occasions (cf. the Journal du Conseil international pour l'exploration de la mer, vols. VI, 1931, VII, 1932, and XI, 1936).

The large turbine bag in the possession of the Biological Station was fastened to a wooden frame fitted into a groove in the concrete sides of the gate of the turbine (Figs. 3—4).

The turbine is placed under a concrete floor without hatches or any other apertures leading to the guide vanes. To pour in the fish we therefore used a square wooden pipe, 4 m. long, made of boards and on top provided with a "funnel" made of a bottomless bag (Fig. 5). One of the sections of the turbine grating was tipped forward and through the opening thus made the wooden pipe was conducted down to the turbine. It proved necessary to weight it to force it downwards.

At 14.17 o'clock everything was in order and the experiments were begun.

A. The turbine was started, and three roach marked by cutting off a pectoral fin were put down the wooden pipe to the turbine. At an immediately subsequent tending (Fig. 6), which could be undertaken without stopping the

turbine, two of the roach were caught (23 and 25 cm.); unhurt.

B. At 14.35 o'clock 50 yearlings of rainbow trout (the majority of about 10—15 cm., a few being larger, but not above 20 cm.) (set I) were shot through the wooden pipe. At the subsequent tending at 14.40 only one (15 cm.) was recaptured; it was unhurt.—We therefore had to give up recapturing all the rainbow trout before the next experiment was started.

The following fish were afterwards shot through the turbine:

C. a. At 14.55 o'clock 10 roach (32, 31, 30, 28, 27, 27, 27, 26, 25, and 25 cm.) and 1 rudd (26 cm.).

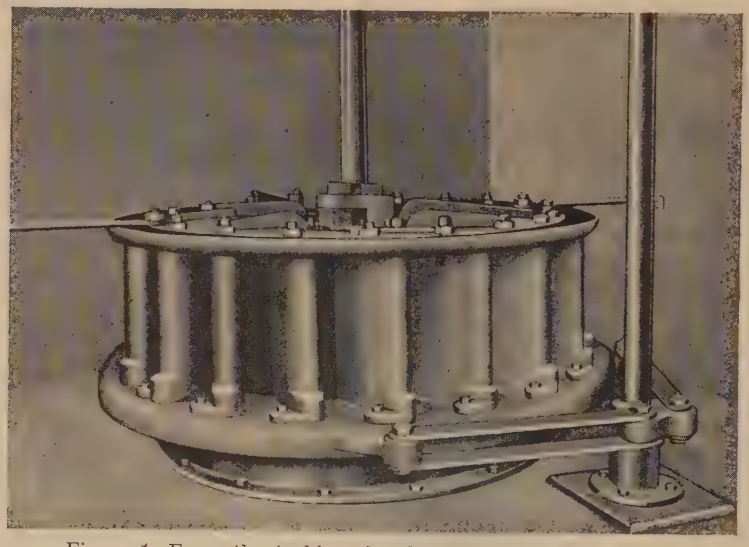


Figure 1. From the turbine chamber of Ribe Midtmølle.

Figure 2. The runner.

b. At 14.58 o'clock 10 perch (28, 26, 24, 22, 22, 21, 20, 20, 20, and 20 cm.).

c. At 15.00 o'clock 2 pike (both 55 cm.).

d. At 15.10 o'clock 22 eels, marked by cutting off one pectoral fin.

The turbine was operated at full charge for 5

minutes. The tending at 15.15 yielded the following recatch:

5 roach (32, 30, 28, 25, and 25 cm.); unhurt.
1 rudd (26 cm.); unhurt.
5 perch (22, 21, 20, 20, and 20 cm.); unhurt.
10 eels.
7 trout (19, 15, 15, 15, 15, 12, and 11 cm.); unhurt.

D. At 15.42 o'clock 50 fairly large yearlings of rainbow trout (about 16—24 cm.) (set II) were shot into the turbine. The tending at 15.50 yielded the following recatch:

1 perch (20 cm.); unhurt.
1 trout (set I) (15 cm.); unhurt.
2 trout (set II) (21 and 20 cm.); unhurt.
1 eel; scraped on both sides, but hardly mortally wounded.

At 16.15 a pole with a wooden plate fastened to the end of it was pressed through the adduction pipe in order to remove possibly remaining fish from it. The pipe then was taken out and the turbine grating was restored to its place.

A tending at 16.40 yielded the following recatch:

2 roach (26 and 25 cm.); unhurt.
2 perch (28 and 25 cm.); unhurt.
1 pike (55 cm.); unhurt.
2 eels.
7 trout (set I) (15, 15, 15, 14, 13, 13, and 12 cm.); unhurt.
25 trout (set II) (24, 23, 22, 22, 21, 21, 21, 21, 20, 20, 20, 20, 20, 20, 20, 19, 19, 19, 19, 19, 18, 18, 18, 17, and 16 cm.); unhurt.
1 roach (cut in halves).

The 13 eels recaptured measured 61, 52, 45, 37, 37, 37, 36, 36, 36, 36, 36, 34, and 34 cm.). 10 out of these were unhurt, but 1 (36 cm.) was rather badly scraped, 1 (45 cm.) probably and 1 (36 cm.) perhaps were scraped in the turbine. It was, however, only a question of superficial abrasions, so that the skin had become blue in the place of abrasion, not of wounds or bruises proper.

The turbine was operated at normal charge till 20.30 o'clock, when it was stopped and the bag was taken out. Out of the fish shot through the turbine the following were recaptured:

4 trout (set I) (15, 15, 13, and 12 cm.); unhurt.
9 trout (set II) (22, 21, 20, 20, 19, 19, 19, 19, and 18 cm.); unhurt. Further 73 river lampreys, 6 eels not marked, 2 small roach (5—6 cm.), 2 burbot, and 2 sea-trout (60 and 34 cm.), both grilse, which had ascended for wintering in the stream.

As appears, a comparatively small number of the fish were hurt. The two turbines, that of the Stampemølle and that of the Midtmølle thus must be considered in the main harmless to the descending trout and salmon smolts; but probably some of the silver eels would be spoilt by passage through the turbines, and hence it is desirable that the eels are caught before getting so far.

Consequently the Board of Fisheries proposed that it be tried to catch the silver eels before their reaching the turbine, and permitted that the gratings in front of the two turbines (cf. the Freshwater Fisheries Act § 11) instead of the normal distance of 2 cm. between the bars be increased to a distance of up to 5 cm., which, of course, means a welcome increase of the water power.

2. Holstebro Kraftstation.

Here experiments were first made on the 14th and 15th of June 1942; as the correctness of the

Survey of Results. Ribe.

Species	Length in cm.	Number put out	Number not recaptured	Number recaptured		Percentage of fish hurt[1]
				unhurt	hurt	
Roach	25—32	13	4	9	1	7.7
Rudd	26	1	0	1	0	0
Perch	20—28	10	2	8	0	0
Pike	55	2	1	1	0	0
Rainbow trout (I)	ab. 10—15	50	30	20	0	0
Rainbow trout (II)	ab. 16—24	50	14	36	0	0
Eel	34—61	22	9	10	3(?)	13.6

[1] The fish not recaptured have not (cf. the last of the reports mentioned p. 79) been considered as hurt; they have probably been able to keep in the current between the turbine and the trap; or some of them may have escaped from the lower mouth of the wooden pipe to the head race, the power of suction hardly being insuperable to the fish.

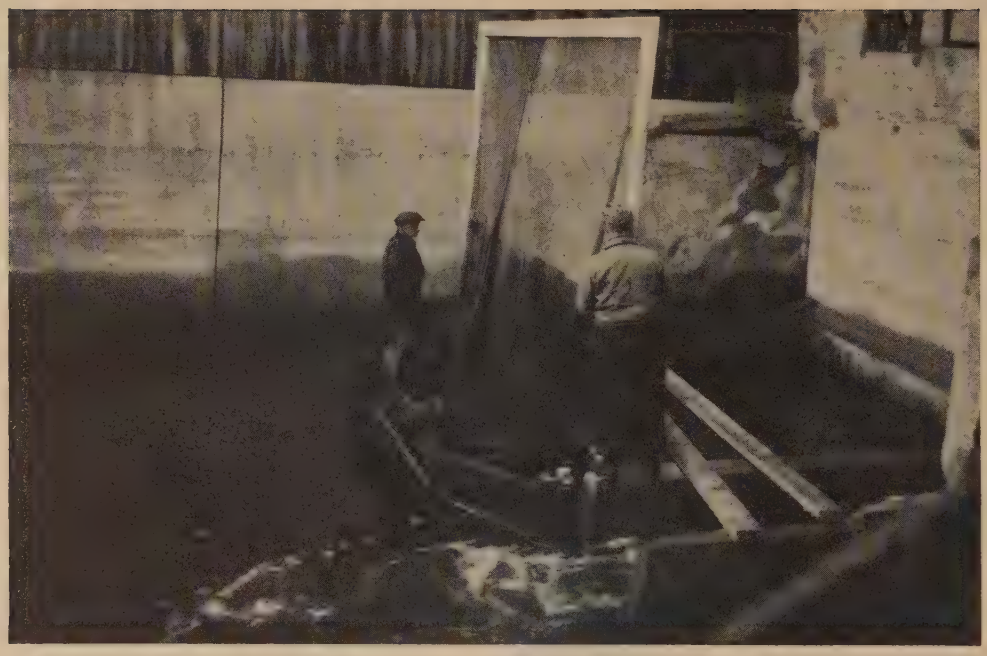


Figure 3. The bag for catching the fish has been fastened to a frame, which is being placed in grooves behind the turbine gate. The dark stripes on the wall indicate the water level a few hours before.

Figure 4. The frame is now nearly in place in the grooves.

Figure 5. The wooden pipe with the "funnel" of sack-cloth round its mouth. A section of the grating has been tipped forward to afford admission to the turbine. The pipe has been tied to a superjacent plank.

Figure 6. The fish are collected from the bag.

result appeared somewhat doubtful, the experiments were repeated in a slightly different form on the 18th and 19th of May 1943.

The power station was taken into use in 1942. It utilizes a head of about 5½ m. produced by a damming of the Storaa. There is only one turbine, a Kaplan turbine of 870 h. p., having a diameter of the runner of about 1500 mm., 4 bucket vanes and constantly 214 rotations a minute. The turbine was supplied by the Czech firm of Idnaz Storek. The vanes are adjustable (Fig. 8), being in a nearly vertical position, thus having a great space between them, when the turbine is running at full charge (about 500 kw.), but being turned more horizontally, thus having a comparatively small space between them, at a low charge (e. g. 130 kw.).

The vertical guide vanes of the turbine (Fig. 8) are placed at some distance from the horizontal runner. The water (and hence the fish) entering below between the guide vanes will flow to the extreme part of the runner, and the fish thus may risk being flung against the surrounding concrete wall or being squeezed between that and the bucket vanes, whereas the water (and the fish) entering above between the guide vanes will hardly come into contact with the concrete wall, but presumably the fish may be hurt by the bucket vanes. This fact occasioned a repetition of the experiments and will be further mentioned below.

The turbine is covered in such a way (see Fig. 7) that there was no possibility of applying the usual method for pouring the fish into the turbine, viz. through a wooden pipe. Instead (as in the Silkeborg experiment of 1935) we had to use a pump hose with a clear diameter of about 10 cm. The hose could be conducted through a narrow opening a couple of metres in front of the turbine immediately in front of the wall of the building, but as the opening passes about 2 metres vertically through the concrete cover, the total length of the hose from the cover downwards must be about 5 metres, and the hose had to be made to bend below the cover towards the turbine. This was arranged by tying on to it a cross-board on which the current was working, and which prevented the hose from being sucked between the guide vanes and damaging the bucket vanes.

The fish were put into the hose and as a rule passed easily through it (see, however, experiment II B). The hose was cleansed with a pail of water. It could not, however, be known with certainty that the fish got out so close to the turbine that the current carried them along; some of them may have escaped against the current, but the results of the experiments showed that at any rate a large number of the fish poured in passed through the turbine. There does not seem to be any probability that by this arrangement the fish should have been carried to the runner in some particularly unfortunate position, as the fish are not carried immediately from the hose to the runner. But as mentioned above, the question may be of importance whether the fish pass between the guide vanes above or below.

Presumably the hose at the first series of experiments was sucked to the guide vanes so that its mouth was carried to the lower part of a slit, the fish thus getting out at an unfortunate place. Hence it was desirable, when the experiments were resumed, to make the hose debouch at the upper end of a slit, and this we tried to obtain (and probably did obtain) by tying a couple of empty oil-cans to the protective boards mounted on the hose. It was further intended to keep the mouth of the hose about ½ m. off the guide vanes, but it is uncertain whether we succeeded.

As regards the Holstebro power station it is considered that the charge may fluctuate between 150 and 500 kw., but that a charge of about 300 kw. will be that most frequently used, and such a charge therefore was chiefly used in the experiments. When the bag was to be tended, the charge, however, was generally increased to 500 kw. for a few minutes for the purpose of possibly driving the fish into the bag. During the tending itself the charge then was made very low, or the turbine was stopped completely, as it was otherwise impossible to work from the barge into which the rear-end of the bag was to be lifted.

Because of the war-time conditions prevalent at the time outdoor photographing was prohibited; hence, only photographs of killed fish and drawings of the turbine can be offered here.

All experiments had to be prepared during the preceding days by construction of a frame for the large bag of the Biological Station. The frame was placed in grooves at the extreme ends of the side-walls of the turbine gate, but on account of the girders supporting the lower grating of the turbine it had to be constructed in three sections.

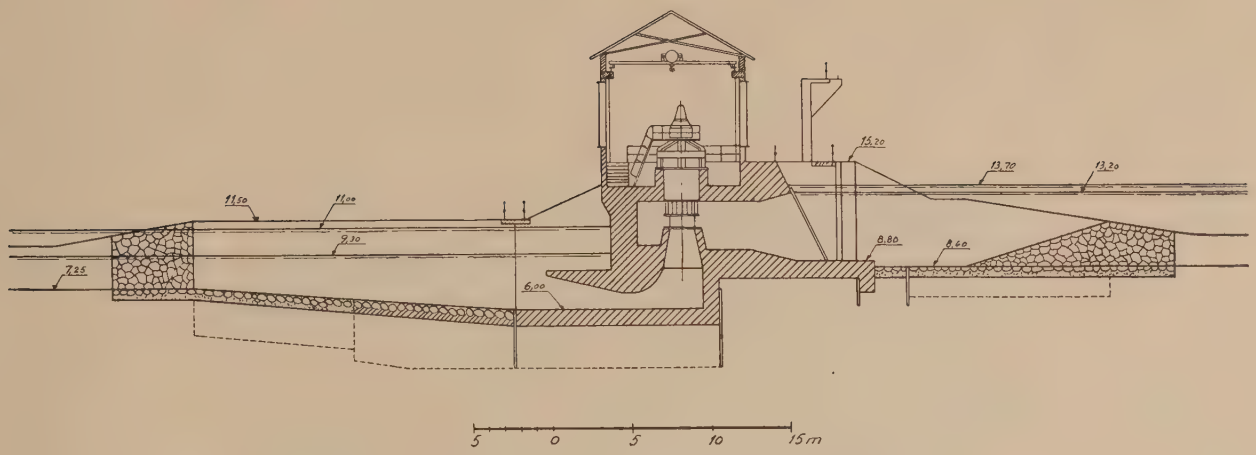


Fig. 7. Longitudinal section of the power station of Holstebro.

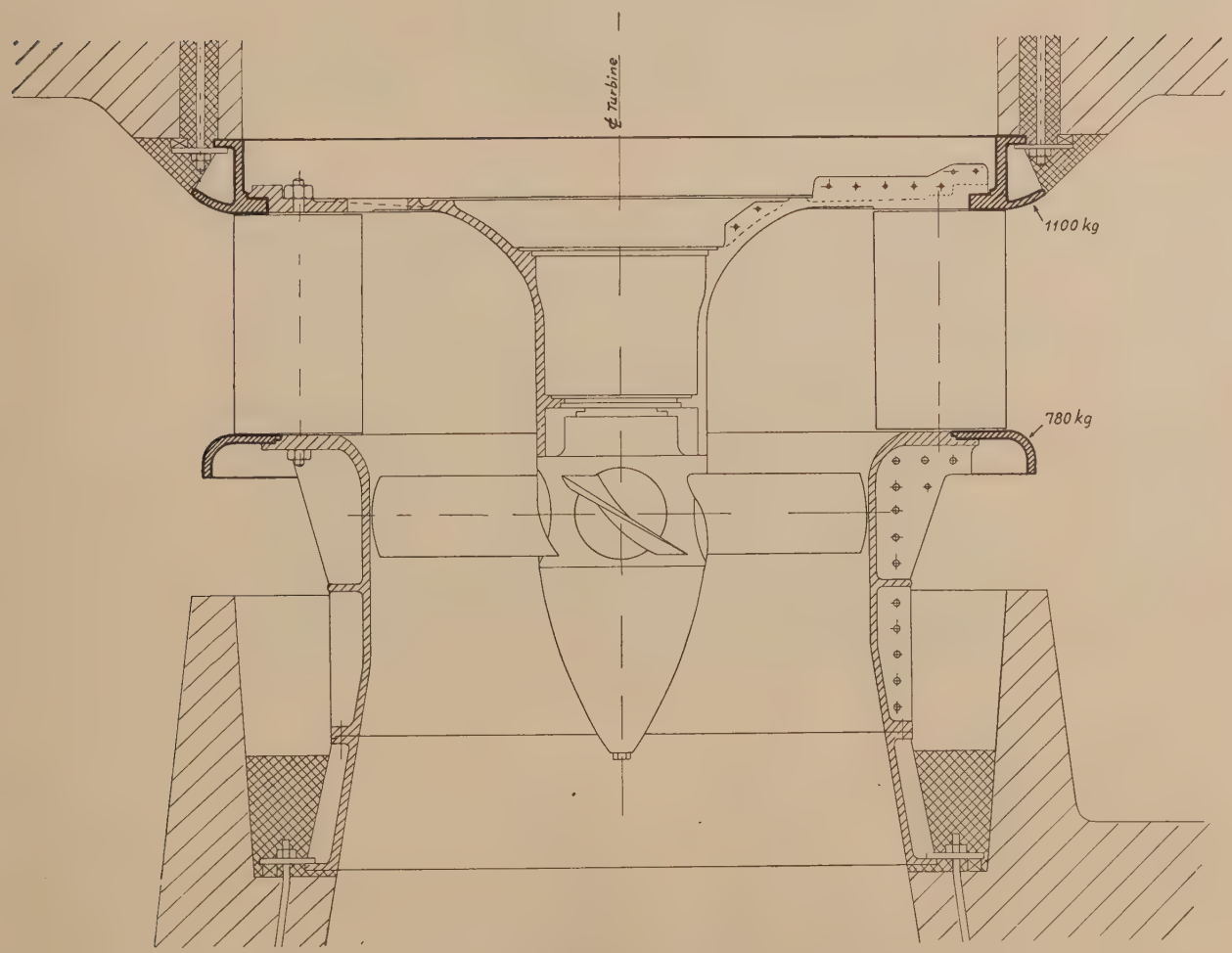


Fig. 8. The vertical guide vanes and the horizontal runner of the turbine.

I. The Experiments made on the 14th and 15th June 1942.

The fish to be used in the experiment were partly rainbow trout (delivered by the pond farm of Fasterholt) in three sizes: (I) 13—17 cm., (II) 21—30 cm., and (III) about 35 cm., partly eels (10 of these measuring 48—59 cm.; the rest were of a similar size) delivered by fishmongers of Holstebro, partly roach (18—25 cm.), dace (18—21 cm.), and pike (40—52), which had been caught in the river on the previous day and kept in caufs at the power-station. Fish which proved to be weak were not used in the experiments. In order to be able to distinguish the test fish from other fish of the same species which might happen to be caught in the bag, roach and eels were marked by cutting off a fin.

The experiments were carried through according to plan; they passed off as follows.

A. At 11.10 o'clock 8 roach were put down, the turbine going at full charge.

At 11.15: tending: 5 roach, unhurt.

B. At 11.30. 25 rainbow trout, set I, and 25 out of set II were sent down, the turbine going at low charge (130 kw.).

At 11.37. Tending:

1 roach, unhurt.
1 — slightly bruised.
2 rainbow trout, set II, both cut in two.

As it was to be supposed that there were some fish in the front part of the bag or in the suction pipe, the turbine was operated at full charge for ten minutes in order to drive them into the rear-end of the bag.

Then the following fish were collected:

5 rainbow trout of I..... unhurt
1 — — - I..... killed } cut
2 — — - II .... killed } in halves.

C. At 12.12. 25 rainbow trout of set I, 23 of set II, and 5 of set III were sent down, the turbine being operated at a charge of 300 kw.

At 12.27. Tending:

Rainbow trout I..... 1 unhurt
— — I..... 1 hurt
— — I..... 3 cut to pieces
— — II.... 7 unhurt
Rainbow trout II.... 1 severely hurt
— — II.... 8 cut to pieces
— — III ... 1 unhurt
— — III ... 1 hurt (back broken)
— — III ... 2 cut to pieces.

The turbine was then going at a charge of 300 kw. for a couple of hours.

At 15.00. Tending:

Rainbow trout I..... 1 unhurt
— — I..... 1 cut to pieces
— — II.... 2 unhurt.

D. At a charge of 300 kw. 13 pike, 5 roach, and 4 dace were sent down at 15.25 o'clock, and at 15.46 24 eels.

At 15.55. Tending:

Pike ..... 12 cut to pieces
Roach ..... 1 unhurt
— ..... 1 hurt
Dace..... 2 unhurt
— ..... 2 cut to pieces
Rainbow trout I..... 2 cut to pieces
— — II.... 2 unhurt
— — II.... 3 cut to pieces
Eel..... 1 unhurt
— ..... 1 hurt
— ..... 1 squeezed and cut in two.

In order to drive out more fish the turbine was operated at full charge for about 20 minutes.

At 16.30. Tending:

Pike ..... 1 cut to pieces
Dace..... 1 unhurt
— ..... 1 hurt
Eel ..... 3 unhurt
— ..... 1 hurt
— ..... 1 cut to pieces
Rainbow trout I..... 3 unhurt.

The turbine then was operated with different charges (17.00 to 19.10 260 kw., 19.10 to 19.45 160 kw., 19.45 to 19.50 450 kw., 19.50 to 20.00 160 kw.).

At 20.00. Tending:

Rainbow trout I..... 2 unhurt
— — II.... 1 unhurt

Eel	1 unhurt	Rainbow trout I	15 unhurt
—	2 hurt, hardly fit to survive	— — II	13 unhurt
		— — III ...	1 unhurt
—	4 cut to pieces.	Roach	1 unhurt

Fig. 9. Eels killed by passing through the turbine.

Fig. 10. Roach and rainbow trout killed by passing through the turbine.

The bag was left overnight. The turbine stood still from 21.00 to 5.00 the next morning. At 7.15 the bag was taken right out; thus the fish found in the front part of it were included, whereas it was impossible to collect the fish standing in front of the bag, in the turbine-gate, and the suction-pipe. The following fish were collected:

Eel	5 cut to pieces, and further 4, also cut to pieces, which could not with certainty be recognized as test fish.

Survey of Results. Holstebro I.

Species	Length in cm.	Number put in	Number not recaptured	Number recaptured		Percentage of fish hurt	
				unhurt	hurt	of those used	of those recaptured
Roach	18—25	13	3	8	2	15	20
Dace	18—21	4	0	2	2	50	50
Pike	40—52	13	0	0	13	100	100
Rainbow trout I	13—17	50	15	27	8	16	23
Rainbow trout II	21—30	48	9	25	16	33	39
Rainbow trout III	ab. 35	5	0	2	3	60	60
Eel	ab. 48—59	24	0 (4?)	5	19 (15?)	79 (63?)	79 (75?)

At several tendings also some fish not used in the experiments were caught. The following species were represented: perch, ruffe, three-spined stickleback, grayling, gudgeon, roach, dace, bream, burbot, and eel.

Kaplan turbines are said to be comparatively harmless to fish passing, and a promise to that effect seems to have been given by the mentioned Czech firm as regards the Holstebro turbine. However, this turbine in the present experiments proved to be far from harmless. This presumably, amongst other things, is due to the fact that the turbine is not as a rule operated at full charge, but only at a lower charge, at which conditions of passage are obviously much poorer than at full charge. The introductory experiment, in which roach were sent through the turbine while this was being operated at full charge, therefore also yielded the best result.

The result may be made up in two ways, as it is necessary to consider both the possibility that all the fish passing through the turbine have been recaptured, whereas the rest have escaped to the head-race, and the possibility that those not recaptured have been standing safely in front of the bag. There can hardly be any doubt that all fish killed or hurt have been driven into the bag. In the case of the eels it took fairly long. This is probably explained by the nine eels collected in the morning of the 15th of June hanging on the runner and not falling off until the turbine was stopped for the night. These eels were extraordinarily much damaged. The skin for the most part was empty, the contents having been flung out. As a rule, however, there were some finger-long pieces left. Even the skin might be so greatly damaged that it was impossible to make out whether one pectoral fin had been cut off or not.

It should be noted that the eels used in the experiment correspond to ordinary silver eels of the point-nosed eels, and that the rainbow trout of set I in length correspond fairly well to descending salmon and trout smolts.

II. The Experiments made on the 18th and 19th of May 1943.

For the experiments a total of 108 rainbow trout were used, partly smaller ones (about 10—17 cm.), partly larger ones (about 18—24 cm.) (delivered by a pond farm at Vemb), 27 roach and 29 eels. To avoid the fish being mistaken for other fish already found in the river, roach and eels were marked by cutting off a pectoral fin. The fishes were put one by one into the pump hose, and this was washed out with water; still there was a mishap (see below). Before each tending the charge for some minutes was increased to 500 kw. in order to drive the fish out into the bag.

A. At 14.51 to 14.54 o'clock 52 small rainbow trout were put into the hose, 2 fell into the water beside it. The turbine was stopped at 15.10.

Tending: 1 rainbow trout, unhurt.
Numerous roach, dace, etc.

B. At 15.35 to 15.41 o'clock 54 larger rainbow trout were put into the hose. Later it appeared that 12 of them had stuck fast in the hose, and so only 42 count in the experiment. The turbine was stopped at 16.00.

Tending: 19 rainbow trout, unhurt.
Numerous roach, dace, etc.
1 brown trout, ♂, 39 cm.

(At 16.35 o'clock 27 roach were put into the hose, which, however, when being washed out with a couple of pails of water, proved to be

Survey of Results. Holstebro II.

Species	Length in cm.	Number put in	Number not recaptured	Number recaptured		Percentage of fish hurt	
				unhurt	hurt	of those used	of those recaptured
Roach	17—23	23	15	7	1	4	12.5
Rainbow trout	11—24	96	25	69	2	2	3
Eel	ab. 35—ab. 61	29	18	2	9	32	82

choked up and had to be taken out. After being emptied of both the roach and the above-mentioned 12 rainbow trout the hose was replaced as before).

C. At 17.32 to 17.40 o'clock 29 eels and 23 roach (of those liberated; fit to survive) were put into the hose. The turbine was stopped at 17.50.

Tending: 8 rainbow trout, unhurt.
2 rainbow trout (of the larger ones), killed.
3 eels, unhurt.
4 eels, killed.
5 roach, unhurt.
1 roach, killed.

The experiment was temporarily ended at 18.40; but the turbine was operated through part of the night and, in order to tire out the fish, was operated at full charge for about a quarter of an hour until it was stopped at 7.00 the next morning. The bag was taken out.

Tending: 39 rainbow trout, unhurt.
2 roach, unhurt.
4 eels, hurt.
Numerous roach and dace, etc., about 50 small eels, 1 eel not used in the experiment (about 40 cm.), bruised.

Out of the fish put down to the turbine it is best to consider only those recaptured. Those not recaptured have either escaped before getting into the turbine, or have got through it unhurt and been able to keep in the current without going into the bag, or they have been killed and have sunk to the bottom before the bag was reached. This last eventuality probably only applies to the eels. The result then may be made out as above.

This result is remarkably better than that obtained in the experiments of 1942. As we may probably in practice consider that the fish enter the turbine evenly distributed over the whole height of the slits between the guide vanes, the actual percentage of fish getting through is probably somewhere between the values found in 1942 and those found in 1943. Obviously so many eels are spoilt that the silver eels ought to be caught before reaching the turbines. On the other hand it seems that we may reckon that the majority of the descending salmon and trout smolts will be able to pass unhurt. Here the fact should be taken into consideration that the length of the rainbow trout used is greater than the normal length of descending trout smolts (10—20 cm.).

Hence, the Board of Fisheries informed the town-council of Holstebro that the Board had no objections to a grating with space of 5 cm. between the bars being used in front of the turbine until further notice, but that the silver eels ought to be caught before reaching the turbine.

Barriers against Fish by Means of Electricity or Veils of Air

By

FRODE BRAMSNÆS, MOGENS JUL,

AND

C. V. OTTERSTRØM

Introduction.

The greatest difficulty in making a good fish pass mostly consists in having the mouths of the pass placed in such a way, that it can easily be found by the fish, there being no great technical difficulties in constructing the passes in such a way, that the fish entering them will also pass through them.

The two mouths of the pass should be placed as near as possible to the weir that stops the passage of the fish, and which the fish must evade by means of the pass. The pass should be straight or, if bends are necessary, larger basins should be constructed at the places in which the direction of the current is altered; this means increased costs and therefore it is often chosen to put the lower mouth of the pass as closely as possible to the weir, the upper mouth being placed at a greater distance. In planning a fish pass at a weir already present it is often impossible to place any of the mouths of the pass as near to the weir as would be desired in consideration of the passage of the fish.

The idea has therefore been put forward that it must be possible to lead the fish to the pass if they are somehow prevented from going past its mouth. In smaller streams this may of course be done by means of a grating, but such a grating must be watched in order to prevent a choking by drifting plants, leaves, etc. Moreover, if the stream has been dammed up for the purpose of procuring water-power, it is a great disadvantage that the grating will diminish this power. It has therefore been proposed (C. V. Otterstrøm: Fisketrapper, Ferskvandsfiskeribladet, Lyngby near Copenhagen 1936) to examine whether it is possible to regulate the passage of the fish in a way so as to avoid a weakening of the current, for instance by means of an electric field.

In Sweden and Germany electricity has been used in different ways for the capture of fish during recent years. They are stunned and taken out by means of a catcher before they recover. The theoretical basis of this procedure was examined by Dr. Friedrich Schiemenz and Professor Karl Humburg and described in the Zeitschrift für Fischerei, Vol. XXXVII, No. 3, April 1940, pp. 429—458.

This and other works made it more probable that it might be possible to regulate the passage of the fish by means of electricity. Such ideas have also been advanced elsewhere, which among other things appears from a communication by letter from Germany and from the fact that Dr. Gunnar Alm (Sötvattenfisket. Stockholm 1942, p. 123) concerning barriers against fish says that in some cases also electrical barriers are used. But as far as we know no experiments have been made for the purpose of elucidating the technical and biological aspect of such barriers.

During a discussion between C. V. Otterstrøm, M. Sc., and J. E. Gerhard, the civil engineer, the latter advanced the idea that it might be possible to make such barriers by means of veils of air formed by small bubbles rising from a perforated tube placed transversely on the bottom of the stream.

The topical interest during recent years in the question concerning fish passes has given rise to a proposal from the Board of Fisheries that a series of experiments should be carried out by Fiskeridirektoratets Forsøgslaboratorium (i. e. the Research Laboratory of the Board of Fisheries) in order to clear up these problems. The experiments were made in the hydraulic laboratory of Danmarks tekniske Højskole (i. e. the Royal Technical College of Copenhagen) in collaboration with the Danish Biological Station. Weber and Balslev, the civil engineers, have taken part in the experiments.

Electrical Barriers.

Principle.

When two electrodes with different voltage are placed in water the electric field between them will act upon fish approaching the electrodes. The experiments aim at clearing up the possibility of stopping the fish in this way without hurting or stunning them by the electric currents.

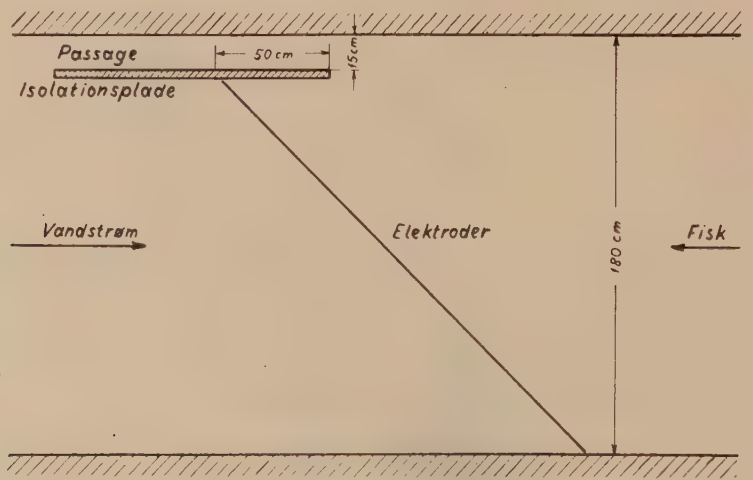


Fig. 1

Fig. 1. Experimental canal and arrangement viewed from above. (Passage—Insulating plate—Water current—Electrodes—Fish).

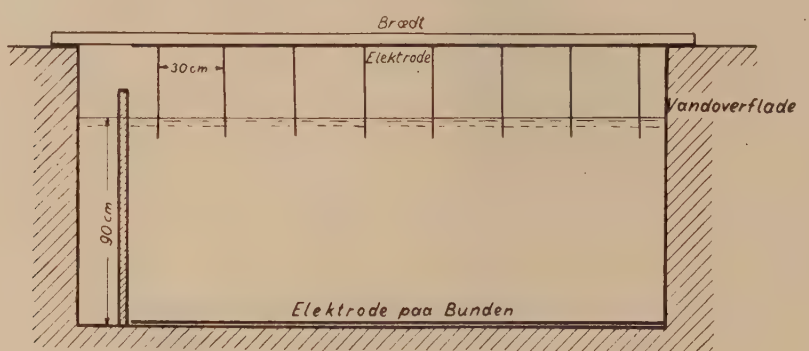


Fig. 2

Fig. 2. Cross-section of experimental canal. In this case the upper electrode is rake-shaped. (Board—Electrode—Surface of water—Electrode on bottom).

Choice of the Shape of the Electrodes.

In the said paper by Dr. Friedrich Schiemenz and Prof. Karl Humburg an account is given of the electrical conditions of a number of different shapes of electrodes. In the present case it seems to be adequate to use one of these types, the bar-shaped electrodes, which are placed vertically from surface to bottom on either side of the stream or horizontally with one electrode placed immediately below the surface, the other on the bottom.

It seems to appear from the literature that the effect of electricity on the fish depends on the total voltage acting upon the fish and not, as might be expected, on the voltage per cm. in the fish.

If two vertical electrodes are used, a fish entering the electric field and moving in the longitudinal direction of the stream will be exposed to an electric influence acting mainly from one side of the fish to the other. If the fish now tries to turn off in order

to get out of the field, the influence will act in the direction from head to tail. It is true that in the latter case the influence is the same per cm., but on account of the extension of the fish in this direction its absolute value will become much greater. If, however, we use one electrode on the bottom and one at the surface, the influence will in all cases be the same whether the fish is swimming lengthwise or crosswise in the stream. For this reason the latter arrangement has been chosen in the present experiments.

Experimental Canal.

The water canal at our disposal for the experiments (Figs. 1—3) was rectangular in cross-section, being 180 cm. wide and 180 cm. deep. The depth of the water could be varied between 60 and 130 cm., and by means of various circulating pumps the water of the canal could be given a velocity of 5—6 or 12—15 cm./sec. In the side-wall of the section of the canal used for the experiments there were some glasses, through which the reactions of the fishes in the electric field could be studied.

Fig. 3. The experimental canal in the hydraulic laboratory of the Royal Technical College of Copenhagen. The three nets seen in the figure are used for controlling the fish during the experiments. The fish are retained within the remotest section, from which they are admitted to the experimental arrangement. When this has been passed by the fish, they are stopped by the net in front. To the left in the experimental arrangement a plate is insulating a passage along one wall of the canal. A rake-shaped electrode is hung obliquely across the canal.

Arrangement for the Experiments.

Parallel to one side of the canal a plate of insulating material (Etronit) was placed at a distance of 15 cm. from the wall of the canal and in such a way that the fish swimming between the plate and the wall were protected against the influence of the electric field. The aim of the experiments now was to put up a barrier obliquely in the remaining part of the canal, thus directing the fish through the protected passage.

During the first part of the experiments the two electrodes used were made of brass bars with a cross-section of 3×9.5 cm. One electrode was placed on the bottom of the canal and the connexion established by means of an insulated cable. The other was hung beneath a board in such a way that its elevation above the bottom could be regulated according to the level of the water. During the experiments the upper electrode was kept 2—5 cm. below the surface. In front of and behind this barrier the canal was closed by means of nets stretched on frames. By means of a third frame with net the fish to be used for each experiment were retained immediately below the barrier. During the experiments they were released one by one.

According to the paper by Dr. Friedrich Schiemenz and Prof. Karl Humburg quoted above the necessary power of the field in the water between the electrodes must be put at 5 volts per m. at least. The necessary voltage between the electrodes and the electric power passing through the water can then be calculated from formulas that are also given in the said paper.

If the distance between the electrodes is put at 1 m., the length of the electrodes at 2.5 m. and the specific resistance of the water at 10 ohms m^2/m., the necessary difference of voltage between the electrodes will be about 15 volts and the corresponding current 1.5 ampere. From this the electric resistance from one electrode to the other is found to be 10 ohms.

The experiments were made with alternating current from the main supply, and the voltages to be used were procured by means of a transformer and rheostats.

Fish for the Experiments.

For the experiments the following fish were used:

Rainbow-trout, portion fish	length	30—35 cm.
Rainbow-trout, setting fish	—	6— 8 cm.
Pike	—	40—50 cm.
Carp	—	35—40 cm.
Eel	—	70—80 cm.

The fish were bought partly from a fishmonger in Copenhagen, partly from a pond farm. The fish were not fed during the 14 days of the experiments.

Velocity of current and depth of water.

During the experiments the depth of the water was about 90—100 cm., the distance between the electrodes about 85—95 cm. This depth of water was obtained by using the medium-sized circulating pump of the laboratory. The corresponding rate of current was 5—6 cm./sec. This is a comparatively slow current and it turned out to be insufficient for the purpose of carrying the fish out of the field when they had been stunned. Therefore some few experiments were made with the largest pump of the laboratory, which afforded a depth in the basin of 120—130 and a current of 12—15 cm./sec. Even this current is rather slow as compared with the rate at which the water normally flows for instance from turbines. Nevertheless it turned out to be too rapid in the present experiments because it proved to be impossible to drive the fish against the current towards the field. So it was necessary to content oneself with the slower current of 5—6 cm./sec.

Difference of voltage between the electrodes.

The experiments were started with a difference of 15 volts between the electrodes. The only fish tried here were portion trout which seemed to pass the field unaffected. The difference then was increased to 25—30 volts, at which voltage most of the fishes used for the experiments were affected, some of them even so vigorously, that it will hardly be possible to use higher voltages without running the risk of hurting the fish. The following results therefore are mainly based on a difference between the electrodes of 25—30 volts. In a few cases experiments were made with a voltage of 35—40, in some of which cases, however, the fish was killed by being exposed too long to the effects of the field.

The Effect of the Field on the Individual Species of Fish.

Trout. The larger trout (the portion fish) stopped at a distance of about 50 cm. from the electrodes,

turned and rapidly swam back following the current. Generally they approached the field several times, but most of them sooner or later found the insulated passage, through which they then passed. A few of them, however, advanced so rapidly towards the field, that they got too far into it, were stunned and turned upside down. When the fish were carried out of the field immediately, either by the slow current or by means of a catcher, they generally recovered after 15—30 seconds and were apparently unhurt. As mentioned, the current was not vigorous enough to carry the fish back at once, and so it happened that some fish remained for a longer time within the field and were exposed to a rather intense stunning. But none of the fish died when there was a difference of 25—30 volts. However, a few fish were killed by the prolonged influence of a difference of 35—40 volts.

The small trout (the setting fish) seemed to pass unaffectedly through all fields used during the experiments, also the 35—40 volts' field. This is presumably due to the small size of the fish. However, setting fish that got very close to the electrodes were generally stunned by the voltage, and if they were not driven off by a vigorous current, they were sometimes killed. But this was the case with very few fish only, and in several cases these small fish, when they advanced along the bottom, were seen to alter their course when they approached the electrodes, rise to halfway between them and then pass the barrier unimpeded.

Pike. The pike behaved in much the same way as the trout. However, their reaction against the effects of the field seemed to be a little slower, and they often advanced too far into the field. The effects on the fish also seemed to be rather more vigorous, undoubtedly on account of the greater height of the pike resulting in a greater extent in the direction of the field. Transitory stunnings on account of the effects of the field were rather frequent during the experiments with the pike.

The pike advanced rather stubbornly towards the field and had some difficulty in evading sidewards, so that they spent a rather long time in finding the insulated passage. On the whole the pike were generally disinclined to advance towards the field when they had once been exposed to its effects.

Carp. It proved to be impossible to drive the carp into the field, but they were very much affected when they were placed within the field by means of a catcher. This may to some extent be due to their greater height.

Eel. Some few experiments were made with eels. These fish showed a greater perseverance than any other of the species: they did not turn round after they had come into contact with the field, but only drew back the front part of the body and tried to advance in another place. In this way they gradually found the insulated passage and went through it.

Modification of the Shape of the Electrodes.

In practical use an electrode hanging horizontally near the surface will presumably cause some trouble on account of drifting vegetation, ice and the like. It was therefore tried to replace this electrode by another shaped like a "comb" or a "rake", the teeth of which dip into the water (see Fig. 2). This proved to be feasible when the teeth were placed sufficiently close to each other. In these experiments a distance of 30 cm. between the electrodes was found to be adequate, but the most suitable distance will presumably vary with the different conditions such as thickness of electrode and depth of water. As might be expected, the voltage between the electrodes in this case had to be raised somewhat, to approximately 50 volts instead of about 30 volts, but the current was nearly the same as during the previous experiments.

Barriers by Means of Veils of Air.

During these experiments much the same arrangement was used as that described above, only that the electrodes were replaced by a perforated tube on the bottom of the canal in the place where the lower electrode had been placed. By means of this perforated tube and compressed air a veil of air-bubbles was formed, stretching from the bottom to the surface of the water.

This form of barrier had a great effect on carp and pike, which could not be driven through the veil of air while the trout seemed to pass entirely unaffected.

Technical causes made it impossible to carry out this experiment in the part of the canal in which the water could be circulated, but we may be allowed to conclude that the effects of such a veil of air will be greater in stagnant than in running water, where the veil to some extent will be effaced by the current.

Result of the Investigations.

The experiments show that the species of fish applied are very sensitive to electrical influences, and it is probable that in arranging an electric field of a certain power across the swimming direction of the fish it will be possible to bar their way effectively. The choice of an adequate voltage will generally deter the fish and make them evade the field. If they enter the field, they will be effected to such a degree only, that they are stunned and carried back by the current; when they have escaped from the field, they will quickly recover and show no signs of being hurt.

These facts only apply to ascending fish in a stream below some power-station. An effective barrier made by means of electricity against all descending fish will no doubt be impossible, because at any rate some fish will presumably enter the field, be stunned, and drift on with the current through the barrier. But it is not totally out of the question that the most sensitive fish, for instance the eel, could be led, so that the method might be applied to secure the migration of the silvery eel.

The experiments further show that if an insulated passage is made beside the field, the fish after some time will find this passage and use it.

The experiments showed that the entrance of such a passage (fish pass) must be situated as closely as possible to the field, but in such a way that the fish are not affected by electricity at the entrance of the passage.

It turned out during the experiments that fields of about 10 volts per m. must be considered adequate, which in the present experiments corresponded to a difference of about 30 volts. The expenditure of power in the arrangement used amounted to about 50 watt. The most practical shape of the upper electrode is no doubt that of a "rake" with teeth dipping into the water. The electrode on the bottom can perhaps be dispensed with in cases when the conductivity of the soil is sufficient.

Some experiments with barriers consisting of a veil of air finally showed that such a veil did not affect the rainbow-trout (*Salmo irideus*); most likely this is also the case with the common trout (*Salmo trutta*), the fish to which the greatest interest is attached in this connexion.

Of course these results have been achieved only by experiments in the laboratory, but it is greatly to be hoped that there will be a possibility of carrying out similar experiments with electrical barriers in nature.[1]

[1] Such an experiment was started in 1943 at Ribe Midtmølle, chiefly for the purpose of trying how the immersed ends of the comb-shaped electrode will react to drifting vegetation and ice.

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